UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE SPILLWAY
GLEN ELDER DAM
MISSOURI RIVER BASIN PROJECT, KANSAS

Report No. Hyd-561

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

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ABSTRACT

Model studies indicated that the initial design of the Glen Elder Dam spillway was adequate for flows up to and including the 264,500 cfs maximum discharge. Spillway discharge is controlled by twelve 50-foot-wide by 21.76-foot-high radial gates and the energy is dissipated by a hydraulic jump stilling basin (Type III). Total drop in elevation from spillway crest to basin floor is 84.4 feet. Tests performed and results recorded include velocity and water surface profiles in the approach channel, water surface profiles throughout the structure, pressures on the baffle piers, erosion in the approach and downstream channels, and discharge capacity and coefficients for the spillway. Training dikes for the approach channel, and five different baffle pier and end sill arrangements in the stilling basin were tested. The shortened baffle pier was used in construction.

DESCRIPTORS-- *dentated sills/ hydraulic structures/ *stilling basins/ discharge coefficients/ discharge measurement/ flow/ Froude number/ hydraulic jumps/ hydraulic models/ open channel flow/ spillway crests/ *water surface profiles/ velocity distribution/ erosion/ radial gates/ IDENTIFIERS-- *baffle piers/ hydraulic design/ Glen Elder Dam, Kan./ Missouri River Basin Project

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HYDRAULIC MODEL STUDIES OF THE SPILLWAY GLEN ELDER DAM MISSOURI RIVER BASIN PROJECT, KANSAS

PURPOSE

Model studies were conducted to determine the hydraulic operating characteristics of the low-head, radial gate-controlled spillway including the approach channel, hydraulic jump stilling basin, and downstream excavated channel.

CONCLUSIONS

1. Approach channel flow was smooth for discharges up to about 200,000 cfs (cubic feet per second). Some turbulence occurred at higher discharges from flow over the approach channel side slopes, Figure 6. Erosion of the approach channel side slopes may occur, at or near maximum discharge with the gates fully opened, Figure 7. Training dikes, placed along the sides of the approach channel, did not eliminate the turbulent flow or erosion of the channel sidewalls, Figure 9. The average flow velocity in the approach channel was about 12.5 feet per second at Station 29+50, Figure 12.

2. The velocity head at the floatwell intake was about 1 foot and equal to the drawdown at that point for maximum discharge of 264,500 cfs and fully open gates, Figure 11.

3. Free flow through the bays was generally smooth except that more water surface drawdown was observed on the left side than on the right side of all piers. Gate-controlled flow was smooth for all discharges. The minimum clearance between the water surface and the gate trunnion pilasters at maximum free flow was 5 feet, Figure 14.

4. The toe of the hydraulic jump surged upstream to Station 33+00 at 264,500 cfs discharge and normal tailwater. This information was used for the placement of the prototype outlets from the drainage galleries.

5. The maximum discharge of 264,500 cfs was obtained at reservoir elevation 1492.2, Figure 17. The coefficient of discharge at 264,500 cfs was 3.59.

6. The hydraulic jump was contained within the stilling basin at all discharges, for all the basin designs tested. The height of the chute and basin sidewalls was adequate to contain nearly all flows. With the "T" baffle piers installed, surging of the hydraulic jump overtopped the basin walls at maximum discharge and normal tailwater.

7. Flow in all basin designs tested moved most foreign material out, and no bed material was brought into the basin from the downstream channel for any discharge. The hydraulic jump did not sweep out with the minimum model tailwater elevation of 1427, or 3.6 feet below normal.

8. Baffle pier pressures ranged from 76 feet of water above atmospheric to 10 feet below atmospheric in the preliminary pier for maximum discharge and normal tailwater; 60 feet above to 4 feet below atmospheric on the short pier; and 32 feet above to 13 feet above atmospheric on the "T" pier.

9. All baffle piers produced a hydraulic jump which stayed within the length of the basin, Figure 29. The short piers caused a more gradual rise of the hydraulic jump. The "T" piers caused a very steep, turbulent jump.

10. Erosion in the downstream channel was minimum when the preliminary baffle piers were installed; slightly more erosion occurred with the short piers; and the "T" type piers caused extensive erosion immediately downstream of the basin.

11. The truncated or short baffle piers were used for the prototype design primarily for structural considerations.

12. All end sills tested produced satisfactory flow conditions which either allowed bed material to remain, or move upstream and lodge against, the end sill, Figure 24A. The solid end sill was used in the prototype design.

ACKNOWLEDGMENT

The model study was accomplished through the cooperation of Spillway and Outlet Works Section of the Dams Branch, Division of Design, and the Hydraulics Branch, Division of Research. Model photography was by W. M. Batts, Office Services Branch.

INTRODUCTION

Glen Elder Dam, situated immediately upstream from the city of Glen Elder, Kansas, on the Solomon River, Figure 1, is the principal feature of the Glen Elder Unit, Solomon Division of the Missouri River Basin Project. The purposes of the dam are flood control and conservation, including irrigation, pollution abatement, and municipal water supply. The earthfill dam embankment is approximately 15,200 feet long at the crest and has a height of approximately 115 feet above the river bed, Figure 2. The principal hydraulic features of the dam are a radial gate-controlled spillway and an outlet works.

The spillway, the subject of this report, includes an excavated approach channel, a concrete gate structure, chute, hydraulic jump stilling basin, and an excavated outlet channel, Figure 3. The discharge is controlled by twelve 50-foot-wide by 21.76-foot-high radial gates, and the total drop in elevation from the spillway crest to the stilling basin floor is 84.4 feet. The energy of flow from the reservoir is dissipated by a hydraulic jump stilling basin. The excavated outlet channel extends for about 4,400 feet in a gentle ogee curve to the Solomon River.

The maximum design discharge of the spillway is 264,500 cfs at reservoir water surface elevation 1492.9. The normal reservoir water surface elevation will be 1455.6 and the top elevation of the flood control pool will be 1488.3. The gates are provided with individual automatic control.

The foundation material at the spillway contains bentonitic shale seams which could reduce the stability of the structure by increasing the sliding factor. This affected the design of the structure, as noted in appropriate sections throughout the report. Dimensions of important quantities used in this report are listed in Table 1 for both English and metric units.

THE MODEL

The tests were conducted with a 1:72 scale model which contained the 12 bays of the overfall spillway, the excavated approach channel, about 1,040 by 1,870 feet of the surrounding reservoir topography, the sloping chute, the stilling basin, and about 2,000 feet of the excavated downstream channel, Figure 4.

The reservoir topography and approach channel were formed in concrete, except for a portion of the left approach channel side slope which was reformed with sand for erosion tests during the study. The spillway crest and downstream sloping chute were constructed of concrete screeded to sheet metal templates. The approach sidewalls, radial gates, and one baffle pier were made of galvanized sheet steel. The piers, chute walls, stilling basin floor, chute blocks, end sill, and remaining baffle piers were made of wood and painted to resist swelling. The outlet channel was formed of sand, with a median diameter of 0.8 mm, so that erosive tendencies of the flow could be determined.

Reservoir elevations were measured by means of a hook gage installed in a stilling well having an inlet located approximately 540 feet upstream from the spillway crest on the centerline of the approach channel. Tailwater elevation staff gages were installed at Stations 36+50 and 50+50 on the downstream channel centerline. Tailwater elevations, Figure 5, were controlled by an adjustable tailgate. Channel bed degradation was not considered in the model study.

Water was supplied to the model reservoir through a 12-inch-diameter pipe connected to the permanent laboratory water supply system. Model discharges were measured by Venturi meters permanently installed in this system. The flow was stilled by passing it through a 6-inch-thick rock baffle.

THE INVESTIGATION

The flow conditions in the approach area, through the bays, on the chute, and in the hydraulic jump stilling basin were observed over the full range of discharges. Erosion tests were made in the approach and outlet channels; pressures on the baffle piers were measured; and a spillway discharge capacity rating was obtained. Performance of the preliminary structure was generally satisfactory. Several modifications were tested but not used in the prototype design, with the exception of the baffle piers which were eventually reduced in height.

Approach Channel Flow

The approach channel flow was generally smooth up to 75 percent of maximum discharge (about 200,000 cfs), Figure 6. The 644-foot-wide approach channel excavated to elevation 1456 was adequate to provide smooth flow for these discharges, and the velocities were sufficiently low to permit the flow to follow the gradually curving channel. At near-maximum discharges, a portion of the water approached the spillway from the sides of the main channel and created some turbulence as it entered the deeper approach channel. This turbulence originated about 500 feet upstream from the spillway crest on the left side and about 600 feet on the right side at 140,000 cfs discharge, and moved closer to the spillway as the discharge increased toward maximum.

Because most of the side flow entered the main channel from the right, the flow direction at the bay entrances was slightly to the left and caused a drawdown of the water surface on the left side of the piers. The water surface drawdown was greatest at both end bays which were the first to flow free as the gates were raised. The turbulence in the approach channel and drawdown at the piers were not severe enough to cause adverse flow conditions in the spillway bays. However, the side flow into the main channel could conceivably cause erosion of the 3:1 side slope of the main channel. To determine the erosive tendencies of the side flow, the left approach channel side slope was formed from sand and an erosion test was run, while holding the reservoir water surface elevation at approximately 1492, and opening the gates by increments. No erosion of the side slopes occurred for gate openings up to 12 feet. Some of the top layer of sand started to form a drift along the top edge of the channel side slope when the gates were opened 16 feet. Severe erosion occurred at maximum discharge (gates fully open) and the eroded material either passed over the spillway or was deposited in the approach channel upstream from the spillway crest, Figure 7. By closing the end gate, the side flow was reduced to the extent that no erosion occurred.

Training dikes.--The side slopes of the approach channel were built up to above maximum reservoir water surface and a dike on each side was extended about 500 feet upstream from the spillway crest to prevent the flow from spilling over the channel sides, Figure 8. Flow around the upstream ends of the training dikes created a drawdown in the water surface, and the velocities reached 9 fps (feet per second) near the upstream ends of the dikes, and 20 fps about 10 feet upstream from the ends of the dikes. Riprap 1 to 4 feet in diameter would be required to prevent erosion of the ends of the dikes and the adjacent channel side slopes.1/ Further tests on the left dike indicated that

1/ "Hydraulic Design of Stilling Basins and Energy Dissipators," Engineering Monograph No. 25, U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, 1963, pp 207-217.

placement of the upstream end of the dike at different angles changed the flow patterns. The flow was smoothest when about 180 feet of the upstream end was placed about 30° away from the approach channel, Figure 9.

Although the training dikes prevented the side flows from entering the channel near the spillway and created smooth flow at the bays, erosion would probably occur at the upstream ends of the dikes. Due to the expense of installing the dikes, the lack of complete protection afforded by them, and the infrequency of operation at near-maximum discharge, the training dikes were *not* included in the recommended design.

Water surface profiles. --Profiles of the water surface in the approach channel were measured to determine the water surface elevation at the intakes to floatwells which are located in the piers to automatically operate the spillway gates. The intakes are located in the approach channel 400 feet upstream from the spillway crest, Figure 10. The drop in water surface between the reservoir and floatwell intakes was needed to properly adjust the automatic gate control mechanisms. Water surface profiles at 50-foot intervals in the approach channel for maximum discharge were recorded, Figure 11. The maximum drop in water surface at the floatwell intakes due to velocity head was about 1 foot.

Velocity measurements. --A velocity traverse across the approach channel at Station 29+50 or 101 feet upstream from the crest axis was recorded for the maximum uncontrolled discharge of 264,500 cfs, Figure 12. The mean velocity measured at 0.6 of the flow depth 2/ was about 13 fps across most of the approach channel. Erratic velocities were recorded in the turbulent region at the right end of the traverse where the side flow entered the main approach channel flow.

Vertical velocity profiles were recorded for maximum discharge at four locations, 106 and 232 feet on either side of the approach channel centerline at Station 29+50, Figure 13. The profiles indicated velocities from 11 to 16 fps throughout the measured depth.

Spillway and Chute Flow

The flow through the spillway bays was generally very smooth. The pier noses, which were slanted about 37° from vertical and rounded in section, Figure 14, caused no turbulence. Excessive approach flow from the right side of the approach channel affected the amount of drawdown along the sides of the piers, as previously described.

2/D. M. Corbet, et al, "Stream Gaging Procedure," U.S. Geological Survey, Water Supply Paper 888, 1943.

Water surface profiles. --Water surface profiles along both sides of five piers and along the right wingwall were obtained for maximum discharge, Figure 14. These profiles show the smooth flow and extent of drawdown along the 4-foot-wide piers. Drawdown at the piers varied from about 0.5 foot at Pier 6 to a maximum of 5 feet, about 4 feet below the average flow surface, at Pier 11. Drawdown along the right wingwall was negligible. The maximum differential head across the piers was 6 feet. The profiles also showed a clearance of about 5 feet between the trunnion pilaster and the maximum water surface under the trunnion. The flow was smooth around the downstream end of the piers. A mild diamond pattern of standing waves on the chute was created where the flow rejoined at the blunt 18-inch-wide pier ends, Figures 15A, B, and 19, but this did not cause adverse flow conditions.

Water surface profiles were also measured along the right sidewall from just upstream of the piers, to the downstream end of the stilling basin, for the maximum discharge of 264,500 cfs and for 19, 25, 50, 75, and 125 percent of maximum discharge, Figure 16. Spot checks of the water surface along the left sidewall showed similar profiles, indicating symmetrical flow in the chute and stilling basin. The height of the chute sidewalls was adequate to contain all flows. Tests with various combinations of gates controlling the flow at maximum reservoir water surface elevation showed sufficient freeboard along the chute walls. The flow rose highest on the chute walls when the left gate was closed and all other gates were fully open, Figure 15C.

The toe position of the hydraulic jump surged upstream to Station 33+00 for maximum discharge, normal tailwater. This test indicated where the prototype subdrain outlets from the drainage galleries should be positioned.

Discharge capacity rating. --Discharge versus reservoir water surface elevation data were obtained for free flow and controlled flow at gate openings of 4, 8, 12, and 16 feet, Figure 17. The gate openings were measured circumferentially along the arc of gate travel, from the gate seat to the bottom of the gate. The seat was at Station 30+56.25 or 5.5 feet downstream from the crest and at elevation 1466.54 or 0.86 foot vertically below the crest. The discharge curve showed that 264,500 cfs could be passed at a measured reservoir water surface elevation of 1491.4, or elevation 1492.2, including velocity head.

A discharge coefficient curve was computed from the free flow discharge rating model data and included in Figure 17. The coefficient of discharge (C_d) is defined as $C_d = \frac{Q}{LH^{3/2}}$ where L equals the total crest length of 600 feet; H equals the head in feet measured from the crest, elevation 1467.40, to the reservoir water surface, measured 540 feet upstream from the crest in the approach channel, plus the velocity head at this point, Figure 18; Q equals the total discharge. The maximum discharge coefficient was about 3.63 for a discharge of 150,000 cfs, while the coefficient at maximum design discharge of 264,500 cfs was 3.59. The slightly lower coefficient at maximum discharge was probably due to the turbulence of the side flow into the main approach channel which moved closer to the spillway crest as the head increased.

Hydraulic Jump Stilling Basin--Preliminary Design

The energy of the spillway flow was dissipated in a Type III 3/ hydraulic jump stilling basin which is relatively short and contains chute blocks, baffle piers, and an end sill. This basin type was selected on the basis of infrequent anticipated usage and maximum construction savings. The incoming flow in a Type III basin is usually limited to velocities of 50 to 60 fps and unit discharges less than 200 cfs. The basin is satisfactory for values of Froude number above 4.0. The Glen Elder design entrance depth (D_1) at the bottom of the chute, was 5 feet with an entrance velocity (V_1) of 82 fps resulting in a Froude number of 6.5 and a maximum unit discharge of 411 cfs per foot of width. An actual model incoming flow depth (D_1), measured close to the toe of the jump for 261,400 cfs discharge, reservoir water surface elevation 1492.2, was 6.5 feet. For this condition, the entering velocity was 62 fps; the Froude number 4.3; and the unit discharge 406 cfs/foot.

The depth (D_2), from the basin floor to the downstream water surface, was designed to be greater than normal minimum. The minimum recommended tailwater depth for the Glen Elder operating conditions is about 31 feet but the design tailwater depth was about 48 feet. The higher tailwater depth was designed to help maintain the jump within the basin to raise the pressures on the baffle pier surfaces and to avoid a basin which would be above the river channel elevation at its junction with the spillway outlet channel. The chute blocks, baffle piers, and end sill were in general designed according to Monograph 25. 4/

Basin and downstream channel flow. --The preliminary basin operated satisfactorily for all discharges, Figure 19. The hydraulic jump was contained well within the basin for all discharges and corresponding tailwater depths. Although some splash overtopped the basin walls at maximum discharge, the sidewalls were adequate in height to contain the flow. Flow entering the downstream channel was smooth and well

3/Ibid.
4/Ibid.

distributed across its entire width. There was about a 3-foot fluctuation in the water surface at maximum discharge.

Tests run at maximum discharge with the minimum tailwater elevation that could be set in the model (about 1427) showed that the jump would remain in the basin for all basin configurations tested in the studies.

Basin self-cleaning tests.--No sand, rock, or other material moved into the stilling basin from the downstream channel during any operating condition. Several tests were run to determine how effectively the flow would remove rock and debris that might be accidentally deposited in the basin. Gravel representing 3-inch-diameter prototype material, placed on the chute in the high-velocity flow at maximum discharge moved out of the basin immediately. Material which represented 1.5-foot-diameter prototype rock accumulated for a short time just upstream of the end sill and then moved downstream out of the basin. Three-foot-diameter material stayed upstream of the end sill and did not leave the basin. Floating material placed in the flow tended to concentrate in the center of the basin where it lingered in the jump for a short time and then moved downstream. As long as the material stayed in the jump, it moved about and occasionally hit the chute floor.

The same tests were repeated for lower discharges. At 75 percent of maximum discharge, the 3-inch and 1.5-foot diameter material stayed upstream of the end sill for a longer time but eventually moved out of the basin. The 3-foot-diameter material remained upstream of the end sill. The floating material stayed in the jump. At 50 percent of maximum discharge, the 3-inch material moved out of the basin much more slowly and all larger material stayed upstream of the end sill. A discharge of 25 percent of maximum moved all rock material to just upstream of the end sill, where it remained. The floating particles had very little action and would not cause damage at this flow. The larger material remained upstream of the baffle piers at 6 and 12 percent of maximum discharge, and the 3-inch material moved to just downstream of the baffle piers. The floating material moved quickly downstream of the basin at a discharge of 2 percent of maximum (5,300 cfs) discharge and all rock material remained upstream of the baffle piers.

Downstream channel erosion test.--The main excavated channel downstream of the stilling basin was 644 feet wide with the invert at elevation 1405.0 and was formed in sand in the model. A 100-foot-wide depressed channel with the invert at elevation 1385 (later changed to 1390) was cut in the main channel. The sides of both channels were on a 2:1 slope. A 3-foot layer of riprap on 18-inch bedding was specified in the downstream channel from the end of the basin, Station 34+85 to Station 36+25, to protect the 5:1 invert slope between the basin and the channel. The riprap was specified after completion of the model studies, however, and was not tested in the model, Figure 20A.

Erosion tests with the preliminary design basin were made at maximum discharge for 2 hours with the tailwater at elevation 1431. The channel topography was leveled by these test flows forming essentially one channel. There was neither deposition nor removal of bed material at the downstream edge of the end sill. The four contour lines on Figure 20B show where the initial channel floor elevations of 1385 and 1405 were located at the end of the erosion test.

Baffle pier pressures. --The baffle pier located immediately to the right of the spillway centerline was made of sheet metal and equipped with 6 piezometers, which were located in areas where previous tests have shown that high impact pressures and subatmospheric pressures might occur. Pressures were measured with single-leg, water-filled, manometers at discharges of 25, 50, 75, and 100 percent of maximum discharge and normal tailwater elevations. No subatmospheric pressures were measured during these tests, Figure 21.

The highest observed impact pressure was 76 feet of water and occured at the base of the upstream face of the pier at maximum discharge. The water depth over the pier at maximum discharge was about 40 feet. Since the pressure at Piezometers 4 and 5 (on the side of the pier) dropped progressively as the discharge was increased, the test was extended to include 125 percent of maximum discharge, and tailwater elevation 1434. The two pressures on the side of the pier dropped to an average 9 feet of water below atmospheric during this test and fluctuated over about 20 feet, Figure 22A.

Instantaneous dynamic and average pressures were also obtained with diaphragm-type pressure cells and electronic recording equipment. The average dynamic pressures recorded were similar to those obtained from the water manometers, Figure 22B. The range in feet over which the pressures fluctuated and frequency rate of the fluctuations are tabulated on Figure 22C. The frequencies were about 1 cycle per second (prototype) throughout the tests. The magnitude of fluctuations, however, greatly increased as the discharge increased, and was greater for Piezometers 4 and 5 than the other piezometers during tests for 50 through 125 percent of maximum discharge. The fluctuations were as much as 80 to 90 feet of water at maximum discharge, and about twice the magnitude of the pressures observed at any of the other piezometers.

Modified Stilling Basin Design

Different combinations of three baffle pier and three end sill designs were tested in the stilling basin, Figure 23. Although they produced different flow conditions in the basin and different erosion patterns in the channel downstream, none of the designs was an improvement on the initial design. However, shortened baffle piers were eventually specified for structural design reasons.

Preliminary baffle piers with dentated end sill.--The solid end sill was changed to one which was triangular in section and included dentates. Although the water surface profile in the basin was nearly identical to that of the initial design, the water surface fluctuation at maximum discharge was about 6 feet, as compared to 3 feet with the initial design.

The channel bed was shaped to the specified configuration, Figure 20A, and an erosion test flow of 50 percent maximum discharge (132,500 cfs), tailwater elevation 1423, was run for 2 hours (prototype). The channel was not greatly changed and the erosion that occurred merely rounded the tops and bottoms of the side slopes of both channels, Figure 24A. The model was operated for an additional 8 hours (prototype) at maximum discharge (264,500 cfs), tailwater elevation 1431. The erosion was quite similar to that observed for the initial design, except that the center of the channel was eroded to elevation 1382, for a distance of 100 feet downstream from the end sill, Figure 24B.

Short baffle piers with preliminary end sill.-- The preliminary design end sill was reinstalled and the height of the baffle piers was reduced by cutting off the tops of the initial piers by 3 feet 9 inches. The short pier was desirable to reduce the excessive sliding factor of the concrete slab on the foundation material. These piers produced a definite change in the water surface profile in the basin, Figure 23. The profile of the hydraulic jump was more gradual and less wave action occurred in the basin. Although deeper erosion occurred at the ends of the basin sidewalls, the erosion pattern in the downstream channel was similar to that observed with the preliminary design.

Short baffle piers with dentated end sill.--The short baffle piers were retained and the dentated end sill reinstalled. Although the average water surface in the basin was about 3 feet higher, the shape of the water surface profile in the basin was nearly identical to that of the previous test with the shortened baffle piers, Figure 23. The erosion of material from around the downstream ends of the basin sidewalls was similar to the previous test. Four distinct shallow dunes formed immediately downstream from the end sill, Figure 24C.

Horizontal end sill apron.--The short baffle piers and dentated end sill were left in place and the sloping downstream side of the end sill was made horizontal, Figure 23. This minor change did not affect the water surface profile and a 2-hour erosion test at 50 percent of maximum discharge caused very little erosion, Figure 25A. Eight hours additional operation at maximum discharge produced an erosion pattern similar to the previous two tests, Figure 25B. The space immediately downstream from the end sill was filled with bed material level with the top of the sill which was initially 9 feet below the top of the horizontal apron. A small area on either side of the basin was eroded away from the sill, slightly exposing the footings, Figure 25C.

Short baffle pier pressures. --Pressures on the surfaces of the short pier were recorded while the spillway was operating at maximum discharge and the tailwater surface elevation was varied from normal (1431) to 8 feet higher and 4 feet lower than normal. The pressures for these conditions are compared in Figure 26. The impact pressures on the upstream face of the pier were from 7 to 15 feet lower than those measured on the full height pier. (The discharge for the full pier test was about 700 cfs higher than for this test.) The pressures along the side of the pier again fluctuated and were as much as 4 feet below atmospheric at normal tailwater and 15 feet below atmospheric with the low tailwater. The pressure measured on the downstream side of the pier was unaffected by the change in height.

"T" baffle piers with preliminary end sill. --The preliminary end sill and left half of the baffle piers were restored and the baffle piers in the right half of the basin were changed to "Sloping 'T' Type" 5/ piers, Figure 28. The "T" baffle piers were placed in the same position, and the upstream face was the same size as the initial piers. The flow in the half of the basin containing the "T" piers was very turbulent and the profile of the hydraulic jump was very steep, Figure 23. The surges of the hydraulic jump rose above the top of the sidewalls at maximum discharge, normal tailwater.

An erosion test at 50 percent of maximum discharge for 2 hours (prototype) at normal tailwater caused very little erosion. Shallow ridges or dunes formed on the 5:1 slope downstream from the basin, Figure 27A. The ridges were evident only in the right half of the basin, downstream from the "T" piers. Maximum discharge operation at normal tailwater for 8 hours (prototype) caused the ridges to greatly enlarge, Figure 27B and C. The ridges extended about 200 feet downstream from the end sill. The valleys between the ridges were eroded as much as 20 feet below the initial grade. Bed material adjacent to the end sill was removed exposing the end of the sill to a depth of 7 feet. No bed material was eroded from the area on either side of the basin, where erosion occurred during the test of the shortened baffle piers.

"T" baffle pier pressures. --Pressures on the "T" baffle pier surfaces were recorded for maximum spillway discharge with normal (1431) and low (1427) tailwater elevations and for 50 percent of maximum discharge, normal tailwater, Figure 28. All recorded pressures were above atmospheric. The pressures were similar to those measured on the preliminary pier. The pressure on the side of the "T"

5/ "Shapes for Appurtenances in Stilling Basins," Journal of the Hydraulics Division Proceedings of the American Society of Civil Engineers, May 1964, by N. Narayana Pillai and T. E. Unny, pp 1-21.

pier was higher at maximum discharge (13 feet at Piezometer 2) than on the preliminary block (3 feet at Piezometers 4 and 5). Nearly identical pressures were observed at 50 percent maximum discharge. The pressure measured on the downstream sloping face of all three piers was essentially identical.

Baffle pier effect on hydraulic jump. --The shape and size of the baffle piers determined the basic profile of the hydraulic jump in the stilling basin, Figure 23. The initial design baffle piers created a steep hydraulic jump which stayed well within the basin and had some wave action. The shortened baffle piers created a flatter hydraulic jump which extended the entire length of the basin and also had wave action throughout this length. The "T" block baffle piers created a very steep hydraulic jump with violently turbulent flow. Photos of the flows demonstrate the three conditions, Figure 29. The end sill had no effect on the profile.

The Recommended Basin

Because of their adequate hydraulic performance and for structural reasons, the short baffle piers were used in the prototype stilling basin. Changes in the end sill design produced no important hydraulic improvements, and the preliminary sill was recommended. In all other aspects, the preliminary basin was recommended.

Table 1

DIMENSIONS OF HYDRAULIC FEATURES

Feature	English units	Metric units
Height of dam	115 feet	35 meters
Length of dam at crest	15,200 feet	4,633 meters
Length of dike at crest	1,300 feet	396 meters
Reservoir area	35,270 acres	143 square kilometers
Reservoir capacity	976,000 acre-feet	1.204×10^9 cubic meters
Spillway design capacity	264,500 cfs	7,490 cms
Head on crest at design capacity	25.5 feet	7.8 meters
Width of crest	600 feet	183 meters
Drop, crest to basin floor	84.4 feet	25.7 meters
Width of basin	644 feet	196 meters
Length of basin	109 feet	33 meters
Height of basin walls	53 feet	16 meters
Radial gate dimensions	50 feet wide	15.24 meters
	21.76 feet high	6.63 meters

FIGURE 1
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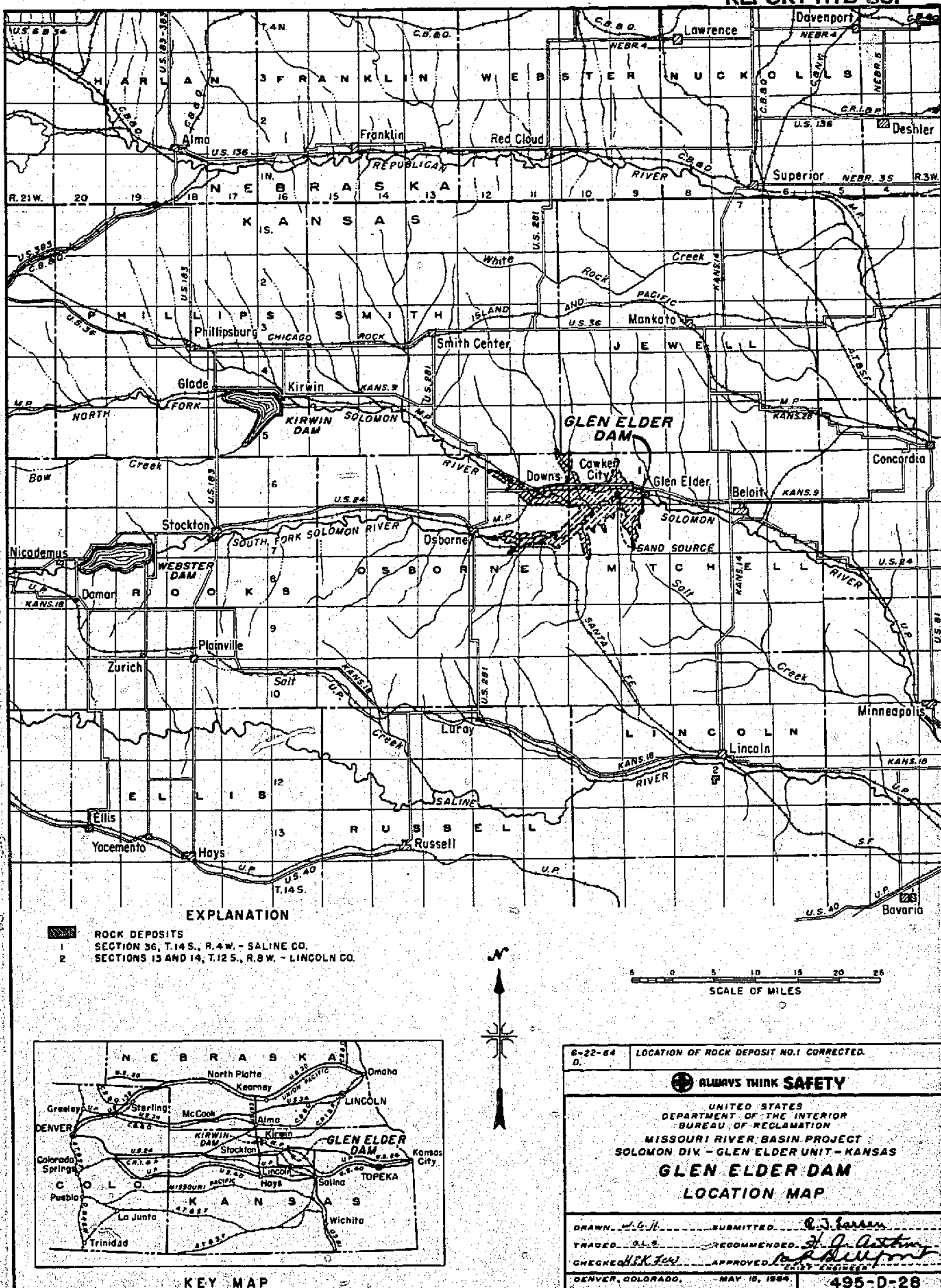
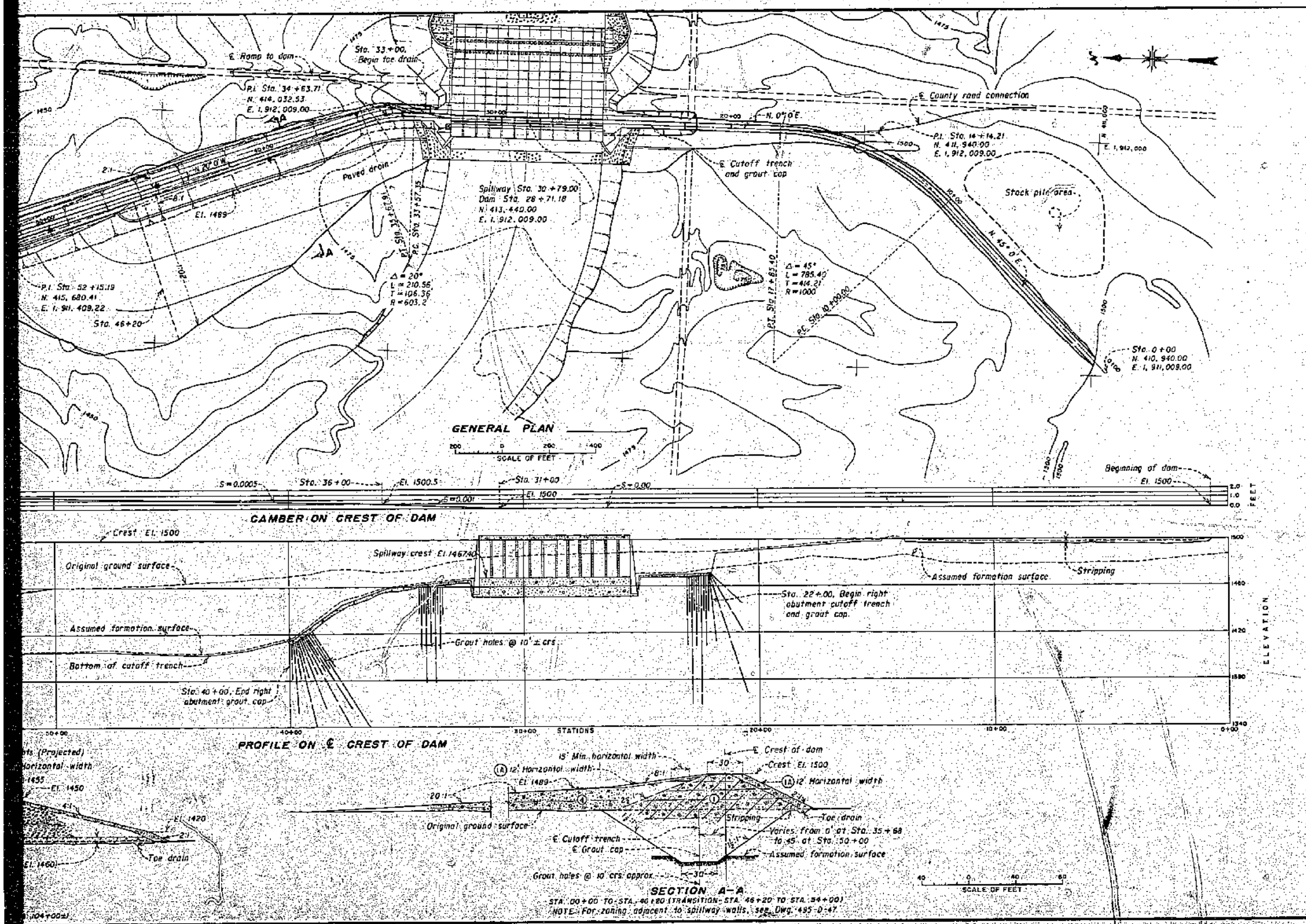
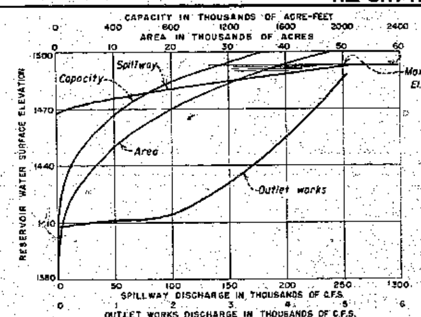


FIGURE 2
REPORT HYD-561





AREA-CAPACITY-DISCHARGE CURVES

RESERVOIR CAPACITY ALLOCATIONS

PURPOSE	ELEVATION	CAPACITY ACRE-FEET
Flood control	1455.6 to 1488.3	736, 900
Irrigation and Municipal	1425.0 to 1455.6	213, 300
Inactive	1407.8 to 1425.0	24, 280
Dead	Streambed to 1407.8	1,520
Total capacity		976,000

A surcharge of 173,000 a.f.* in combination with a spillway capacity of 263,000 c.f.s. is provided to protect against the inflow design flood having a peak of 437,000 c.f.s. and a 3-day volume of 900,000 a.f.
*Max. W.S. El. 1492.9.

EMBANKMENT EXPLANATION

1. Selected clay, silt and sand compacted by tamping rollers to 6-inch layers.
1A. Selected topsoil compacted by tamping rollers to 6-inch layers.
2. Sand compacted by crawler type tractors to 12" layers.
2A. Selected sand or sand with some silt compacted by tamping rollers to 6-inch layers.
3. Limestone and shale fragments to 18-inch Max. size placed in 18-inch layers and compacted by pneumatic tired roller.
4. Miscellaneous material placed in 12-inch layers and compacted by travel of equipment.

8-7-54 LOCATION OF SPILLWAY CORRECTED

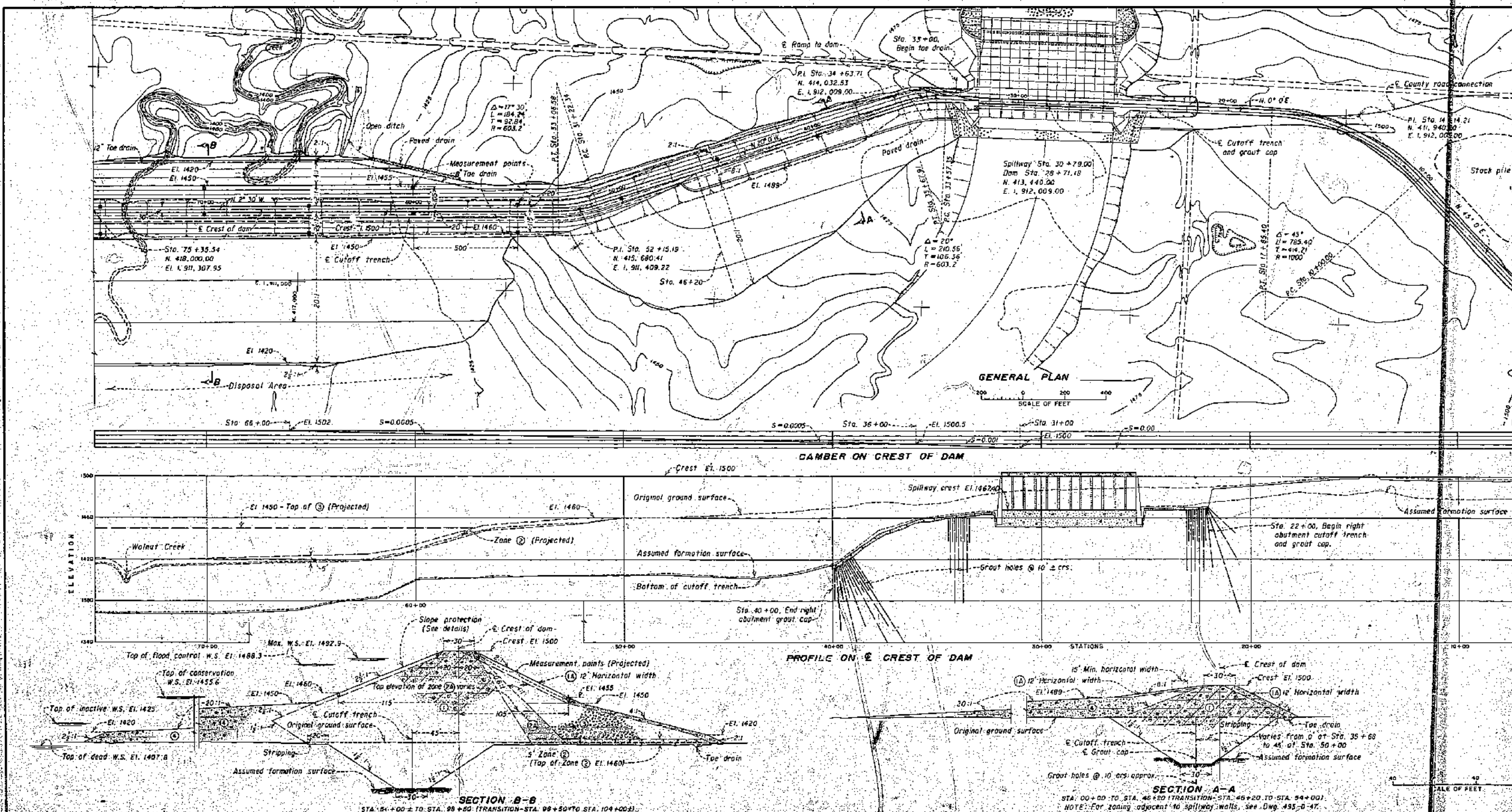
ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
SOLOMON DIVISION - GLEN ELDER UNIT - KANSAS

GLEN ELDER DAM
GENERAL PLAN AND SECTIONS

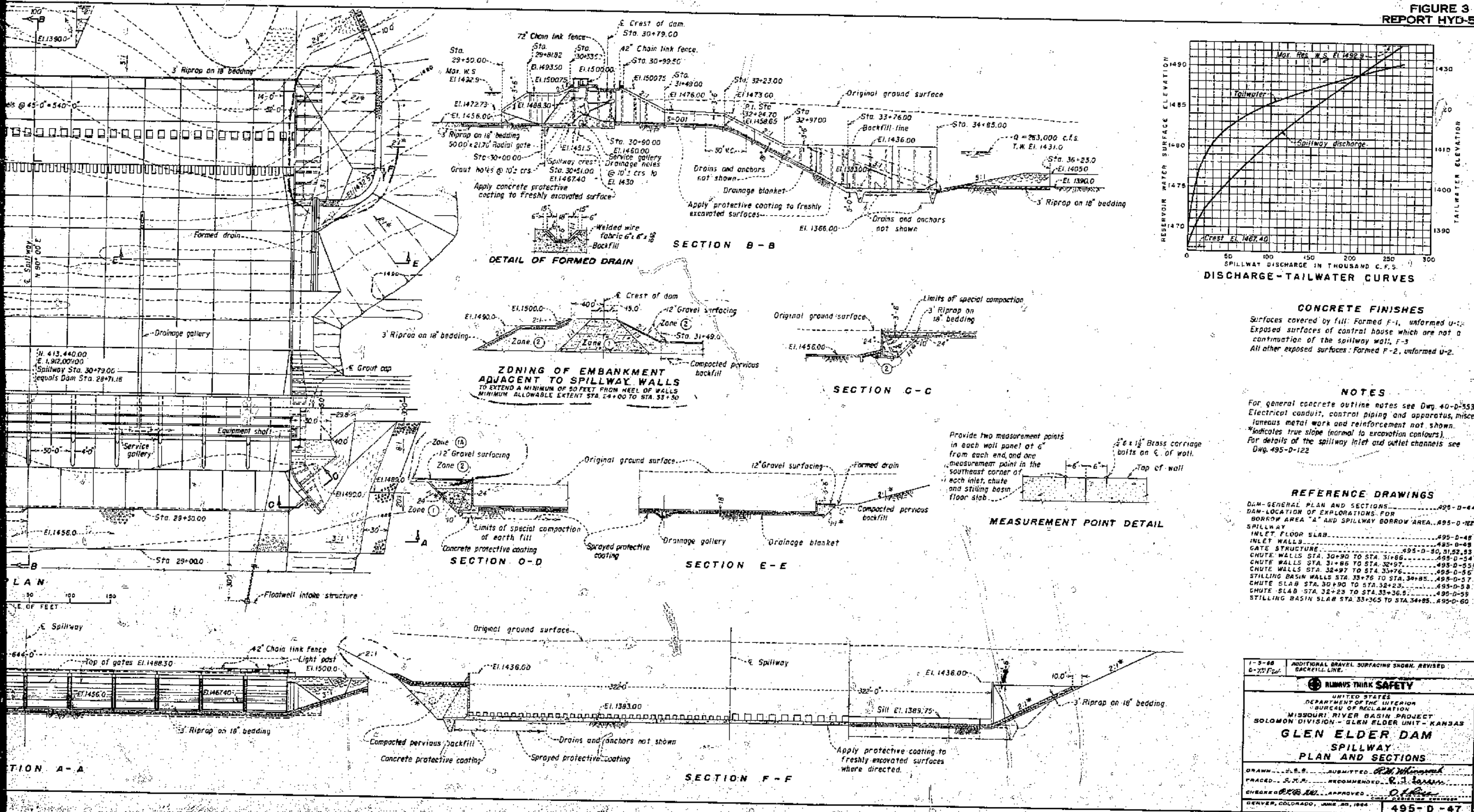
DRAWN N.S.C. SUBMITTED Fred C. Walker
TRACED R.T.Y. RECOMMENDED
CHECKED APPROVED
CHIEF DESIGNING ENGINEER

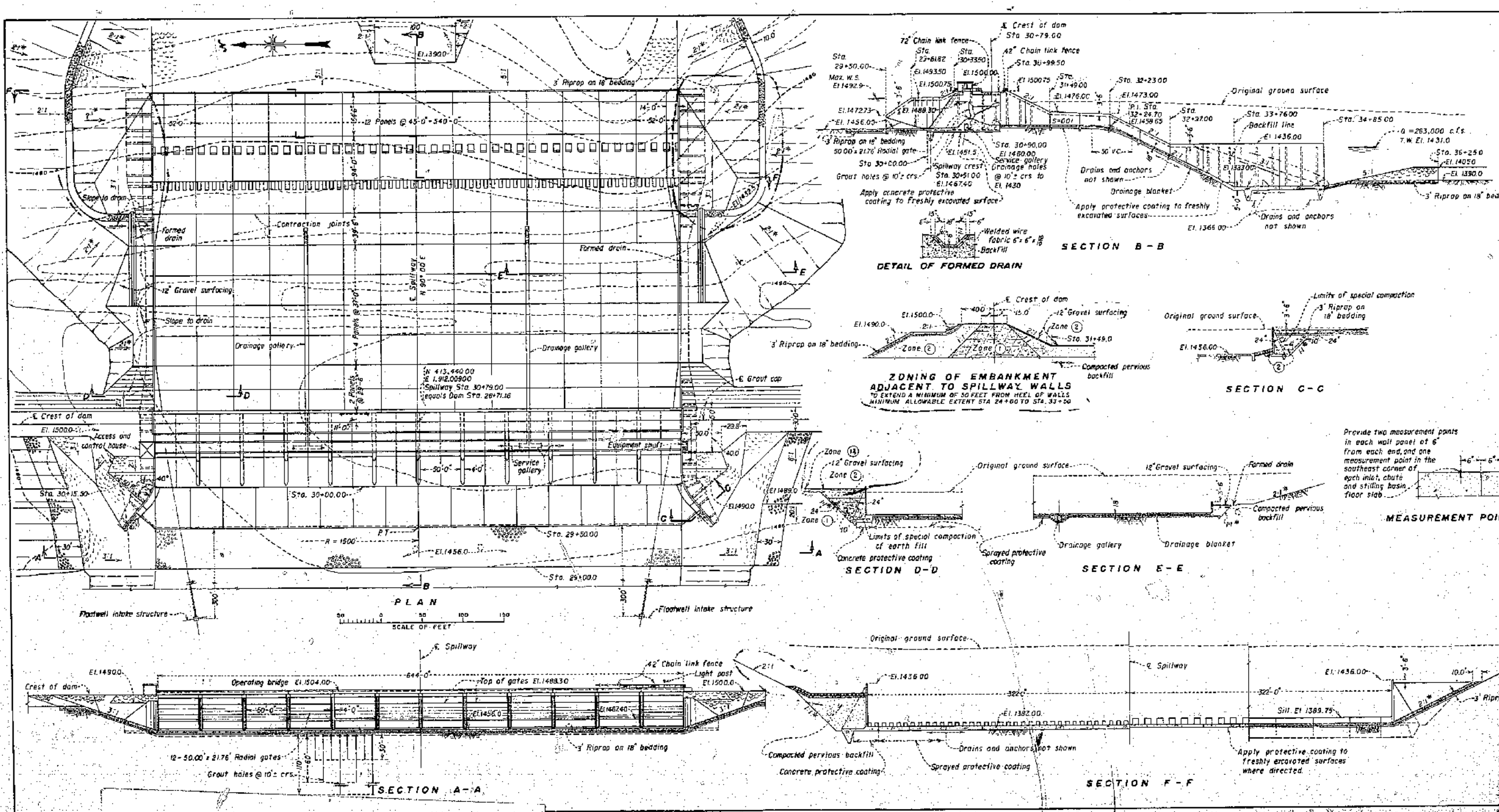
DENVER, COLORADO, JUNE 22, 1954 SHEET 1 OF 2 495-D-44


GENERAL PLAN
SCALE OF FEET
CAMBER ON CREST OF DAM
PROFILE ON ℄ CREST OF DAM
SECTION B-B
STA. 54+00± TO STA. 98+60 (TRANSITION-STA. 98+60 TO STA. 104+00±)
SECTION A-A
STA. 00+00 TO STA. 46+20 (TRANSITION-STA. 46+20 TO STA. 54+00)
NOTE: For zoning adjacent to spillway walls, see Dwg. 495-D-47.
ELEVATION
STATIONS
℄ County road connection
℄ Ramp to dam
Sta. 33+60, Begin toe drain
Spillway Sta. 30+79.00
Dam Sta. 28+71.18
N. 413, 440.00
E. 1, 912, 009.00
℄ Cutoff trench and grout cap
Paved drain
Open ditch
Measurement points
Toe drain
℄ Crest of dam
℄ Cutoff trench
Disposal Area
Walnut Creek
Original ground surface
Assumed formation surface
Bottom of cutoff trench
Grout holes @ 10' ± crs.
Spillway crest El. 1467.40
Crest El. 1500
El. 1450 - Top of ③ (Projected)
Zone ② (Projected)
Sta. 22+00, Begin right abutment cutoff trench and grout cap.
Sta. 40+00, End right abutment grout cap.
Slope protection (See details)
Max. W.S. El. 1492.9
Top of flood control W.S. El. 1488.3
Top of conservation W.S. El. 1455.6
Top of inactive W.S. El. 1425
Top of dead W.S. El. 1407.8
Measurement points (Projected)
Top elevation of zone 2A varies
Stripping
5' Zone ② (Top of Zone ② El. 1460)
Grout holes @ 10 crs. approx.
15' Min. horizontal width
Varies from 0' at Sta. 35+68 to 45' at Sta. 50+00

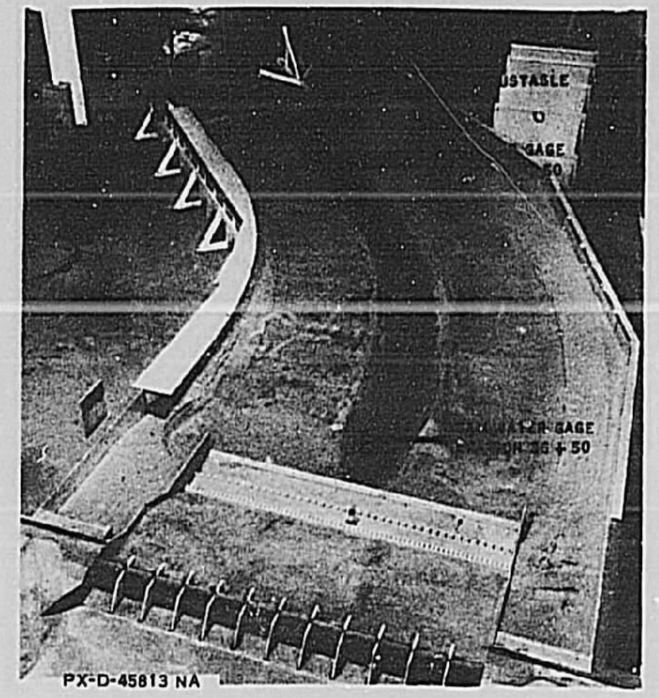
FRAME 2

FIGURE 3
REPORT HYD-561

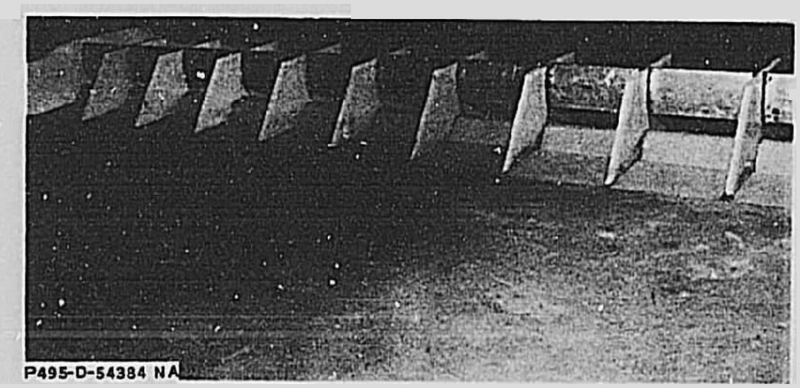



PLAN
SCALE OF FEET
SECTION A-A
SECTION B-B
DETAIL OF FORMED DRAIN
ZONING OF EMBANKMENT ADJACENT TO SPILLWAY WALLS
SECTION C-C
SECTION D-D
SECTION E-E
MEASUREMENT POI
SECTION F-F
Provide two measurement points in each wall panel at 6" from each end, and one measurement point in the southeast corner of each inlet, chute and stilling basin floor slab.
Floatwell intake structure
Operating bridge El. 1504.00
Top of gates El. 1488.30
12 - 50.00' x 21.76' Radial gates
Grout holes @ 10' crs.
3" Riprap on 18" bedding
Original ground surface

FRAME 2



View facing downstream

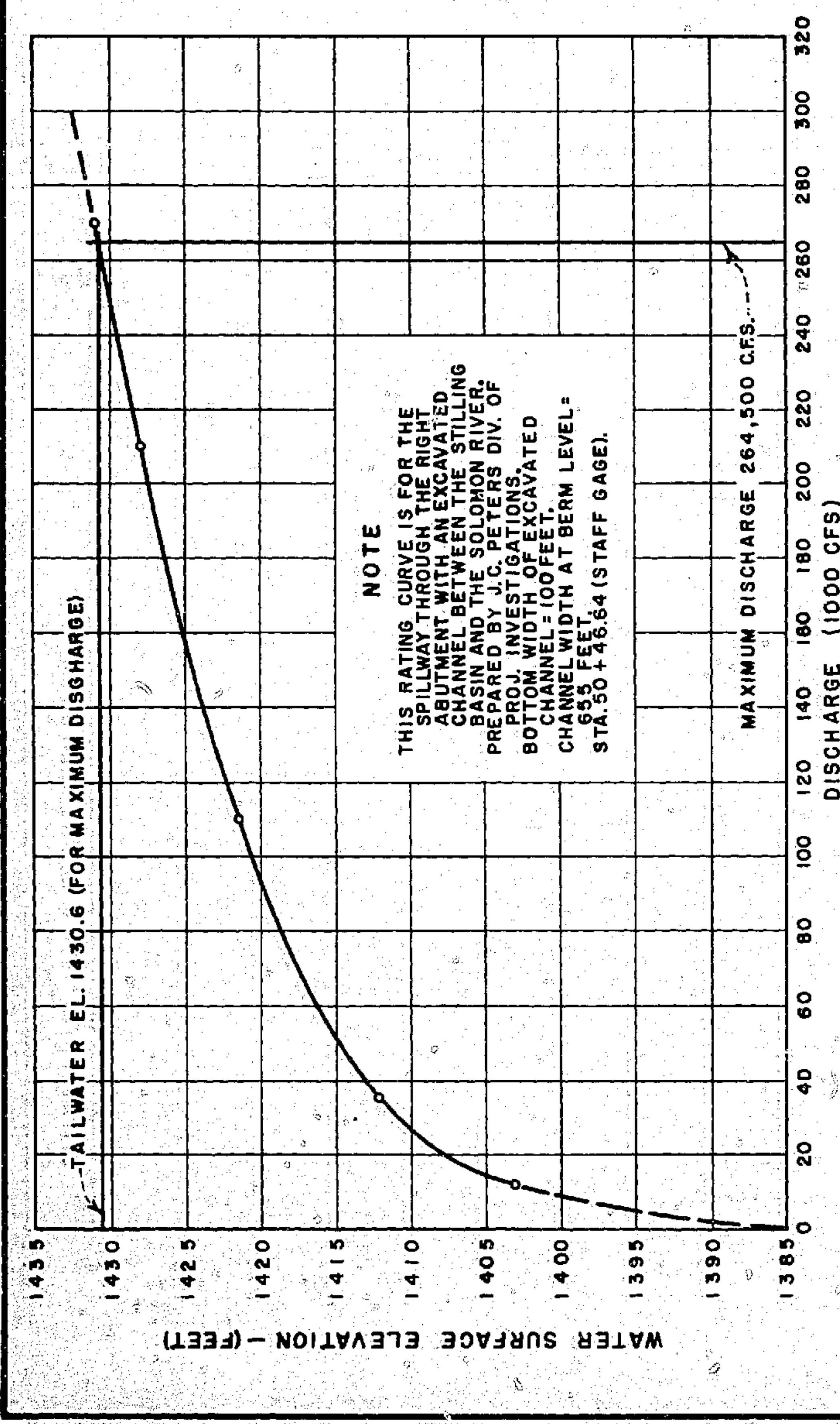


The approach channel showing 10 of the 12
spillway bays

GLEN ELDER DAM
SPILLWAY

The 1-72 Scale Model

FIGURE 5
REPORT HYD-561

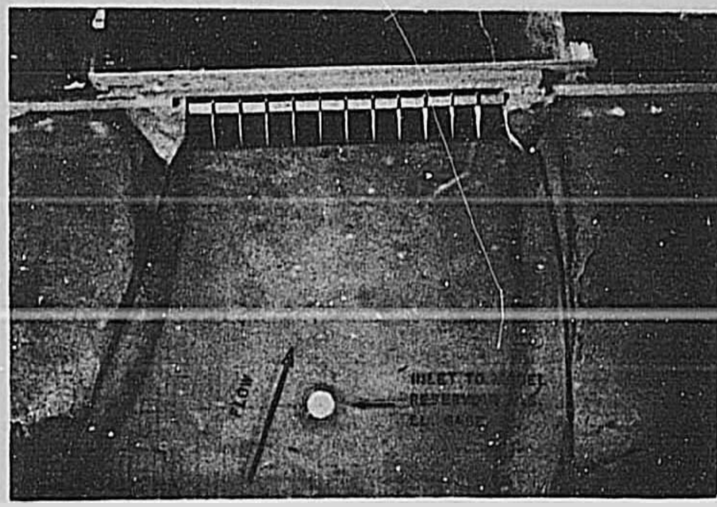


GLEN ELDER DAM SPILLWAY

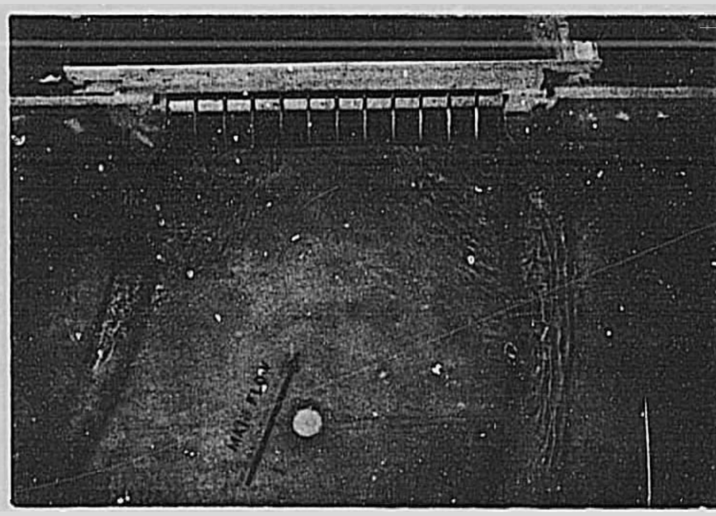
TAILWATER RATING CURVE
(AT UPSTREAM END OF EXCAVATED CHANNEL)

1:72 SCALE MODEL

Figure 6
Report Hyd - 561



Discharge 66,125 cfs (25% of maximum)
Gates fully opened, Res. W.S. El. 1477.3



Discharge 264,500 cfs (Maximum)
Gates fully opened, Res. W.S. El. 1492.2:

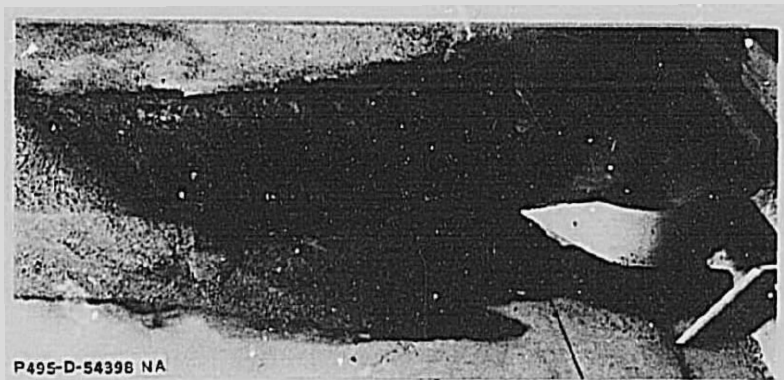
GLEN ELDER DAM
SPILLWAY

Flow In Spillway Approach Channel

1-72 Scale Model

Figure 7
Report Hyd - 561

A. Material eroded from the left approach channel side slope and deposited in the low-velocity areas of the two adjacent end bays and at the stilling basin end sill after 264,500 cfs discharge for 4 hours (prototype)

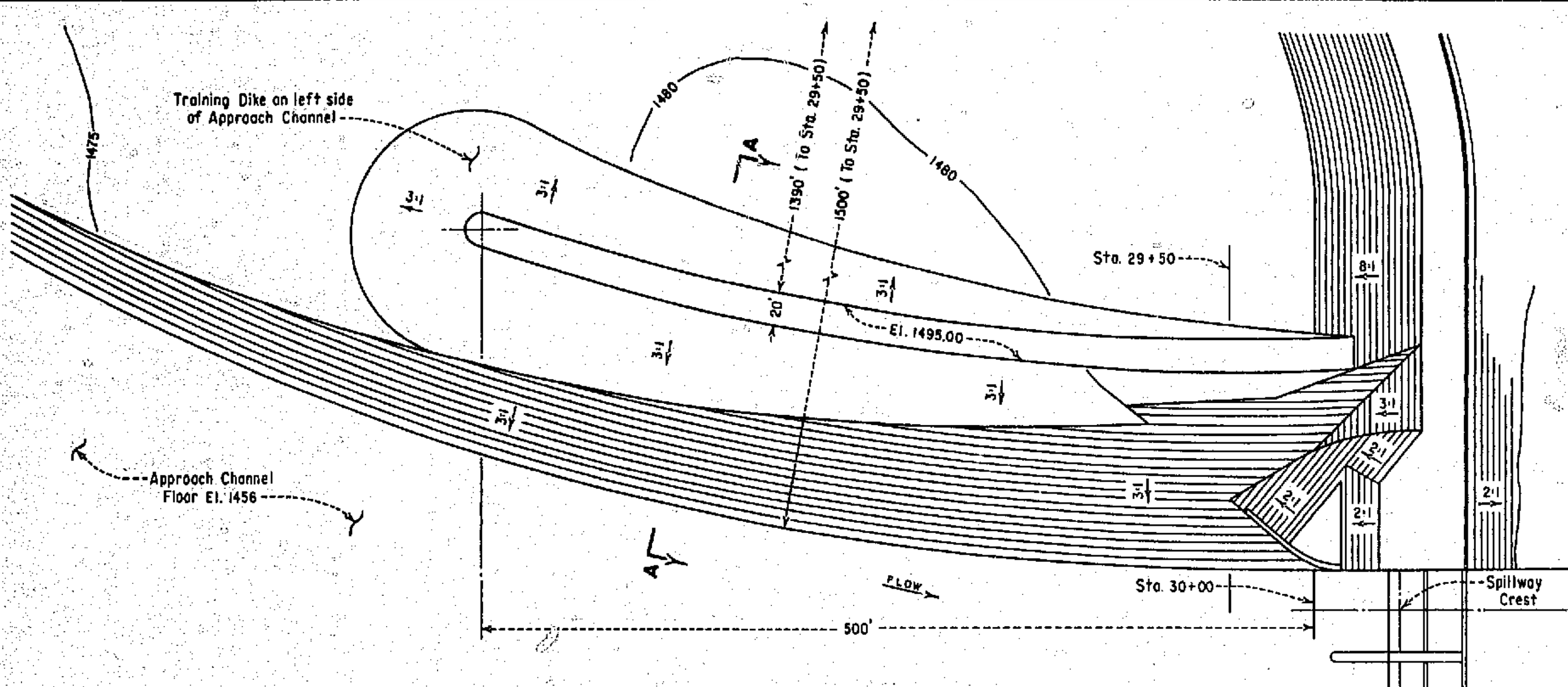


B. The eroded area along the left side slope extended about 350 feet upstream from the spillway crest after operation at the above discharge

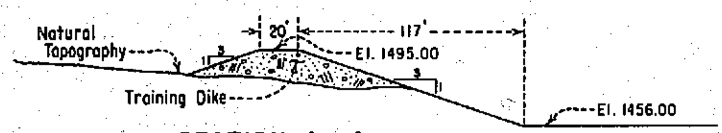
GLEN ELDER DAM
SPILLWAY

Erosion of Left Side Slope of Approach Channel

1-72 Scale Model



PLAN - LEFT SIDE OF APPROACH CHANNEL
(Left side shown - Right side similar)

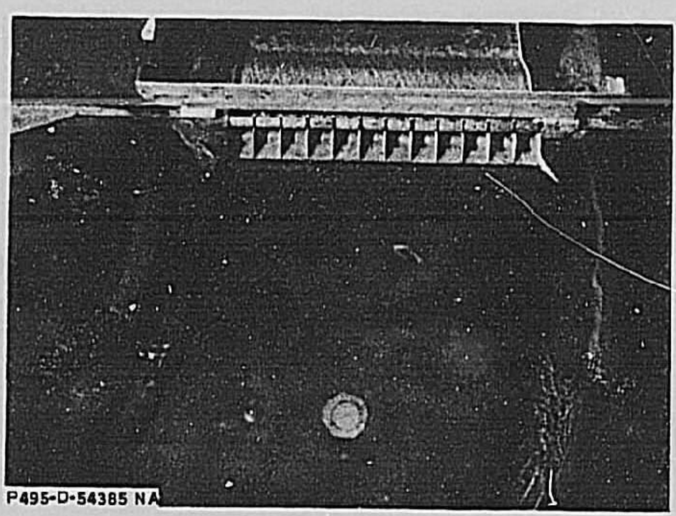


SECTION A - A
Scale (see above)

GLEN ELDER DAM SPILLWAY
LEFT TRAINING DIKE
1:72 SCALE MODEL

Figure 9
Report Hyd - 561

The preliminary left training dike



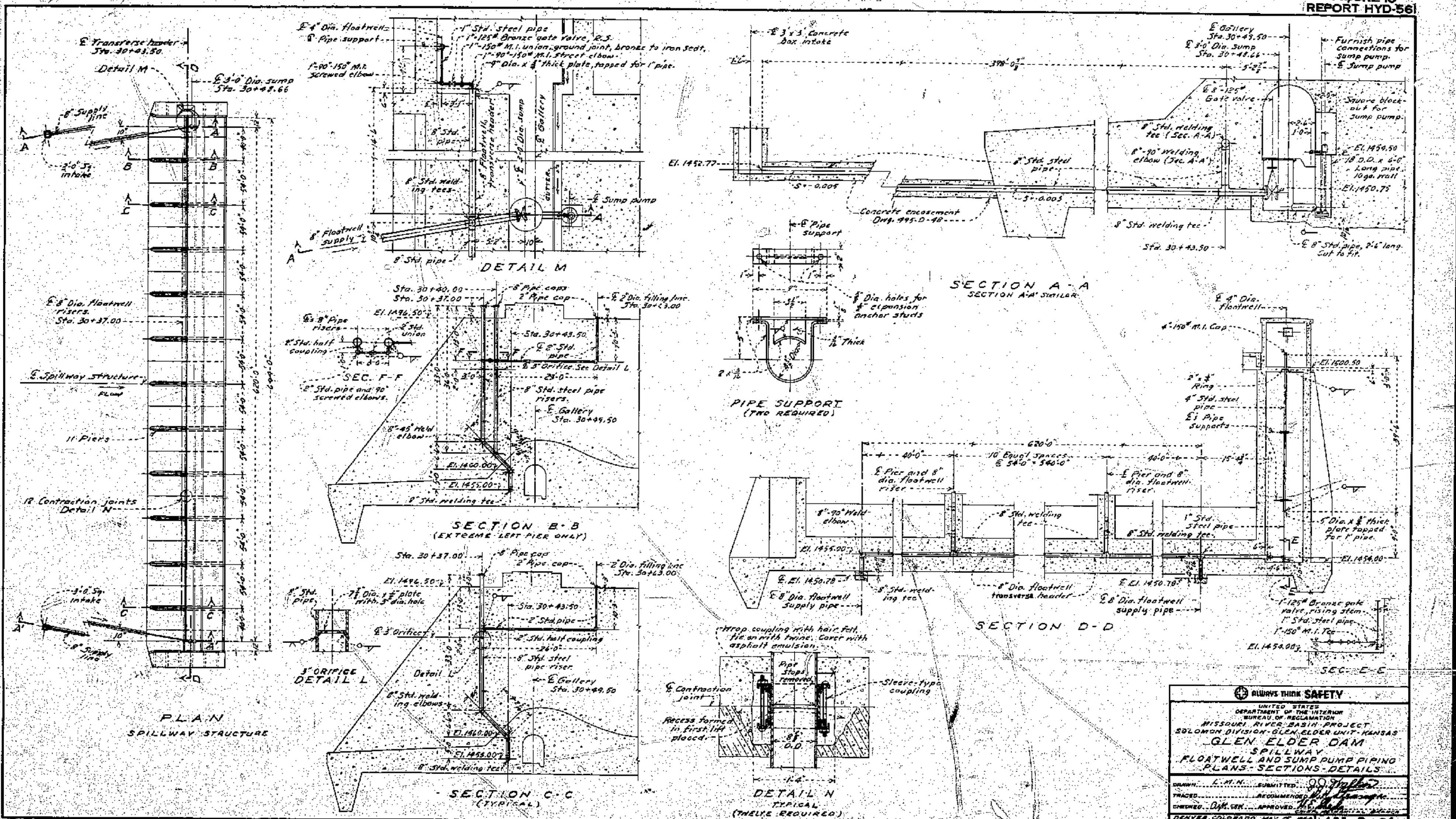
The upstream end of the left dike placed 30° away from the approach channel. Discharge 264,500 cfs; fully opened gates; reservoir water surface El. 1492.2

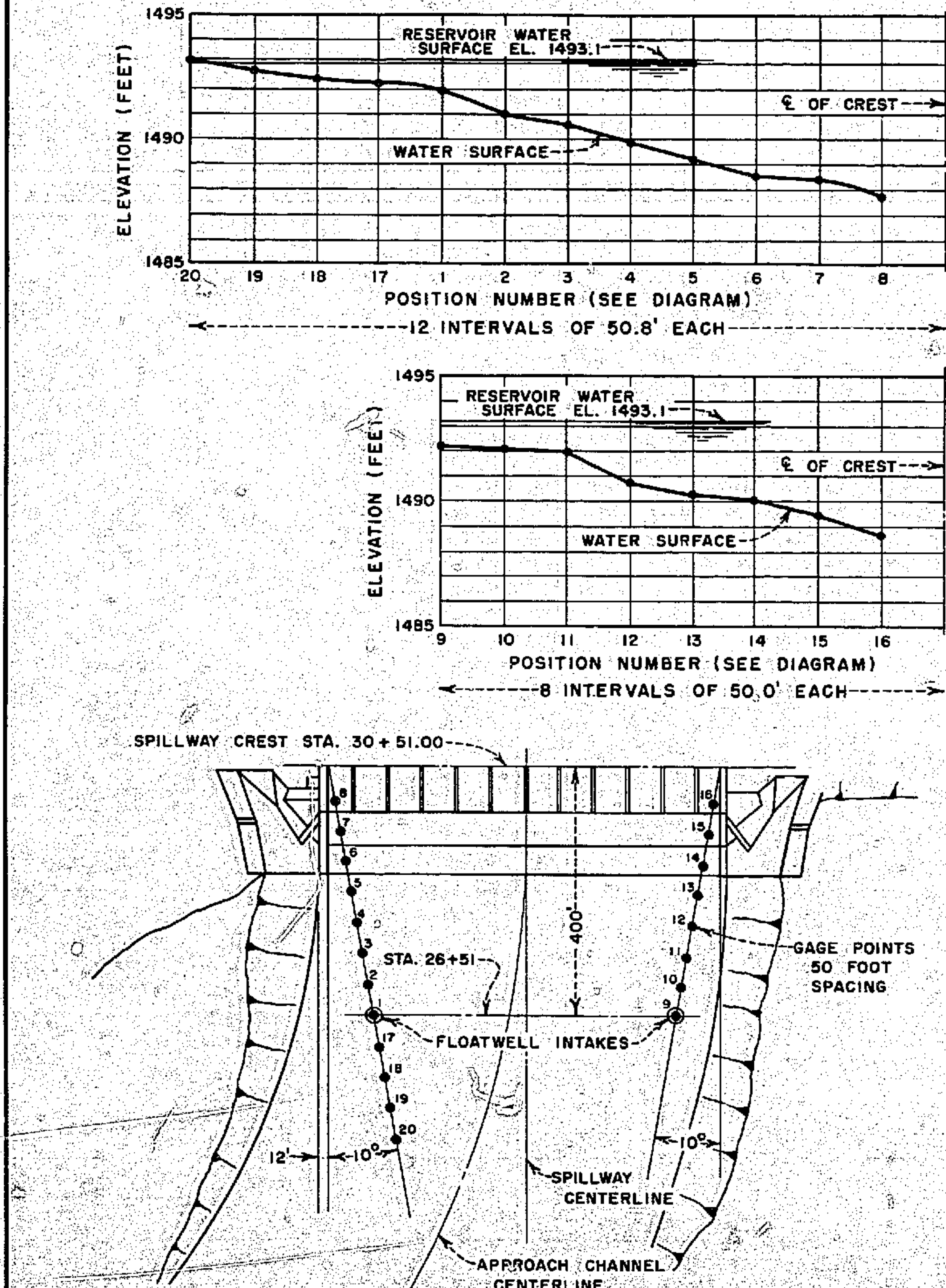
GLEN ELDER DAM
SPILLWAY

Approach Channel Training Dike Tests

1-72 Scale Model

FIGURE 10
REPORT HYD-561





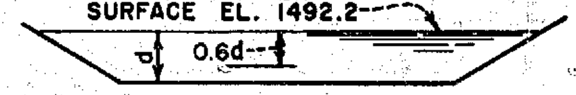
WATER SURFACE GAGE POINT LOCATIONS

GLEN ELDER DAM SPILLWAY

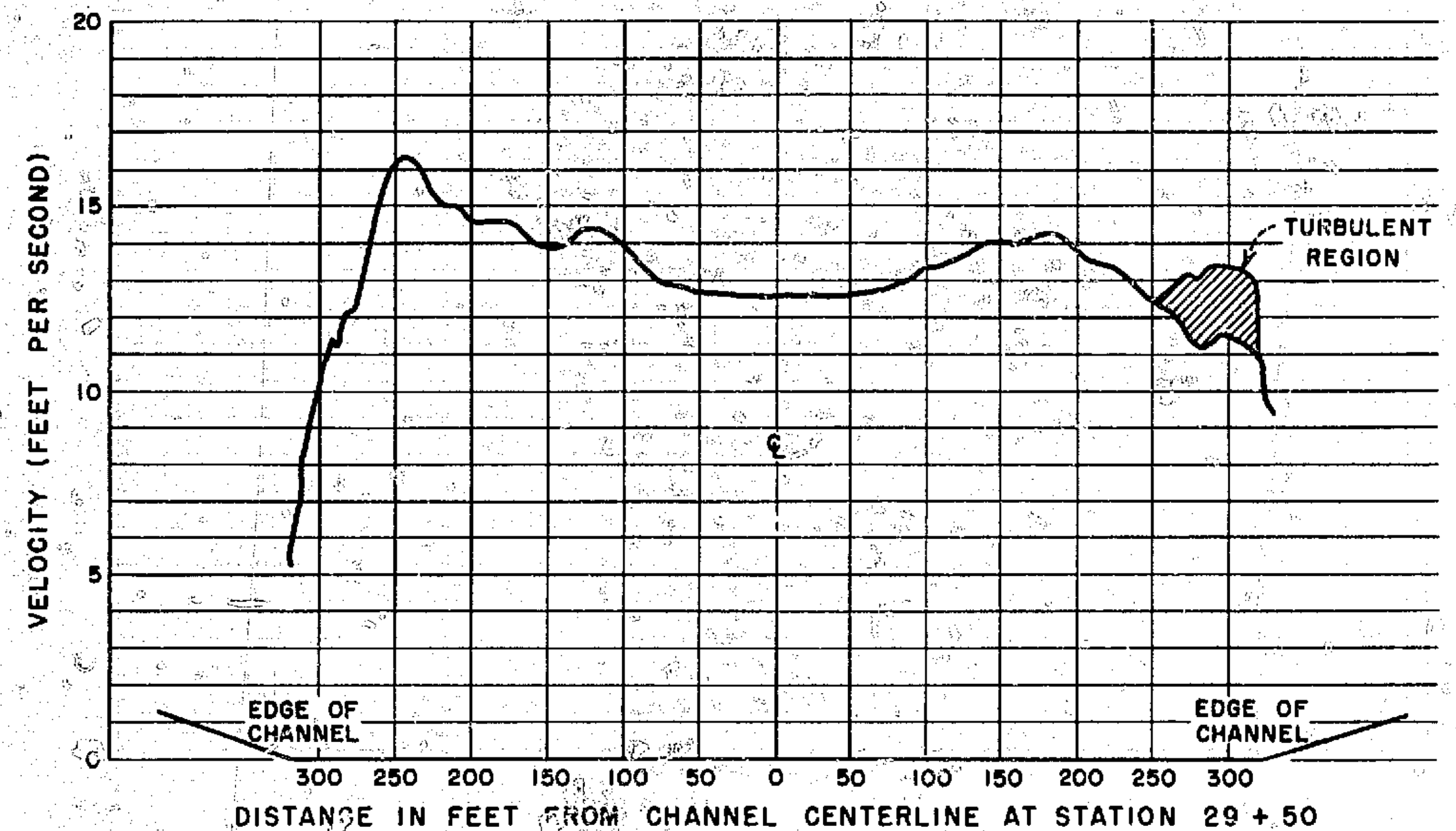
WATER SURFACE PROFILES AT FLOATWELL INTAKE
(DISCHARGE 265,380 CFS)

1:72 SCALE MODEL

FIGURE 12
REPORT HYD-561



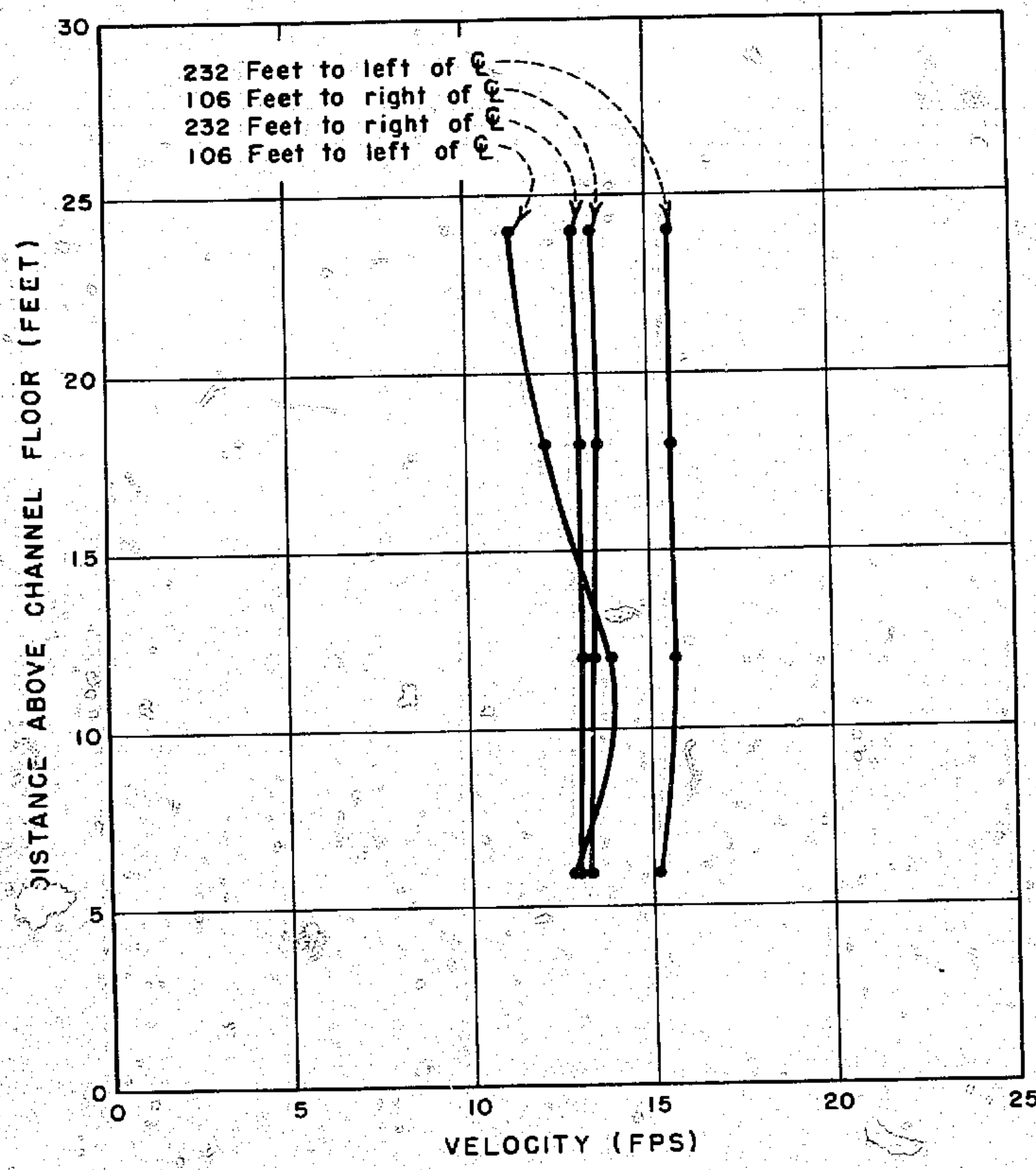
READINGS TAKEN AT 0.6 DEPTH
MAXIMUM DISCHARGE — 264,500 CFS



GLEN ELDER DAM SPILLWAY

APPROACH CHANNEL VELOCITY TRAVERSE

1 : 72 SCALE MODEL



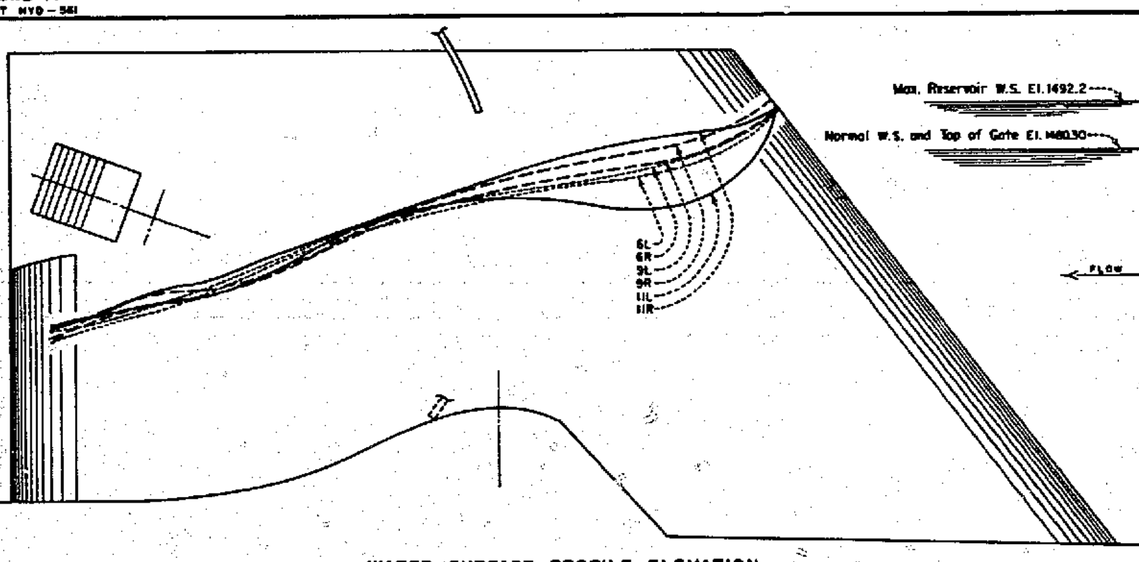
DISCHARGE 264,500 CFS — FULL OPEN GATES

GLEN ELDER DAM SPILLWAY

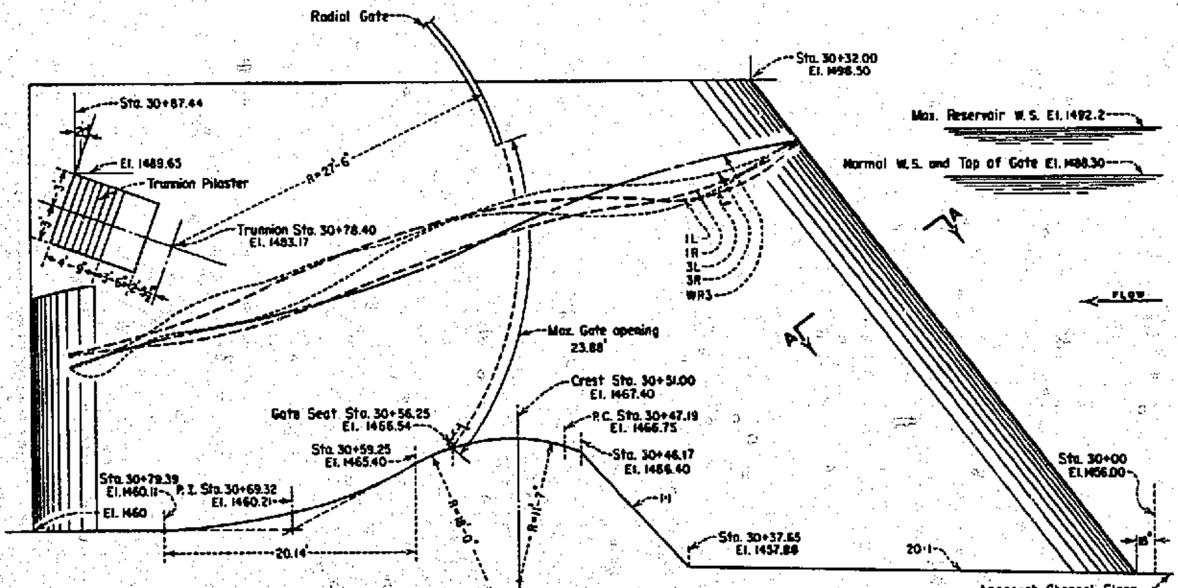
APPROACH CHANNEL VERTICAL VELOCITY DISTRIBUTION AT STA. 29+50

1:72 SCALE MODEL

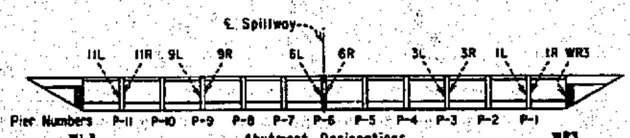
FIGURE 14
REPORT HYD-561



WATER SURFACE PROFILE ELEVATION
Profiles in left half of spillway

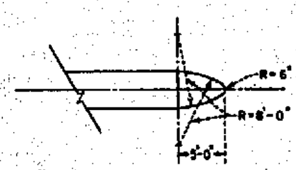


WATER SURFACE PROFILE ELEVATION
(STRUCTURE DIMENSIONS INCLUDED)
Profiles in right half of spillway



WATER SURFACE PROFILE LOCATION SYMBOLS
1L Left side of Pier P-1 (etc.)
1R Right side of Pier P-1 (etc.)

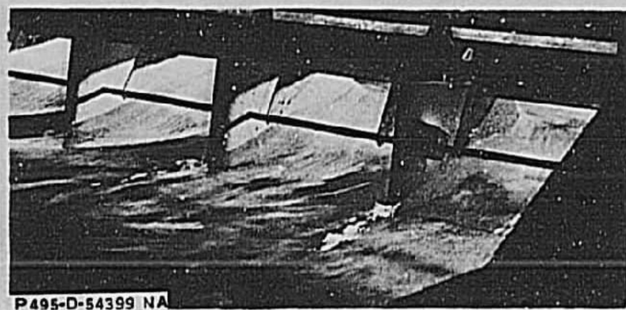
LOCATION KEY — ELEVATION
(Facing Downstream)
no scale



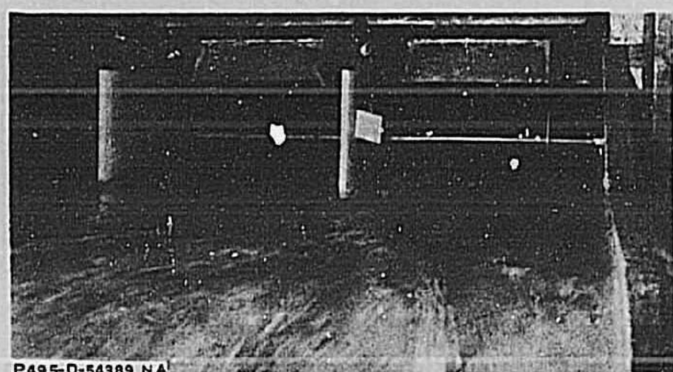
SECTION A—A

GLEN ELDER DAM SPILLWAY
WATER SURFACE PROFILES AT PIERS
1:72 SCALE MODEL

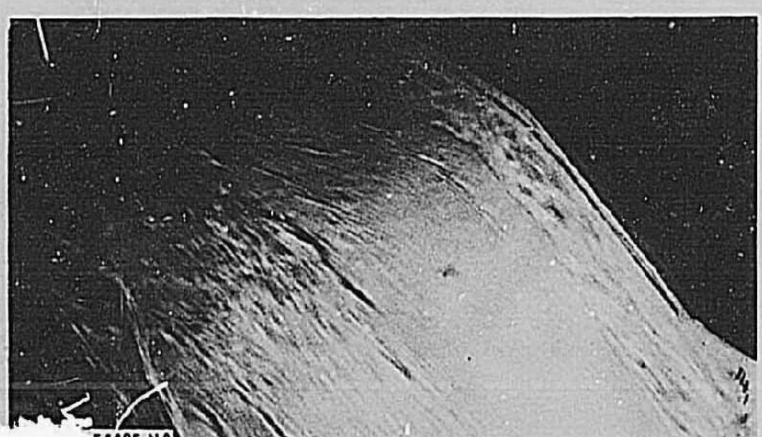
Figure 15
Report Hyd - 561



Flow through bays and clearance of pilaster modeled in the left end bay. Discharge 264,500 cfs; reservoir water surface El. 1492.2



B. Flow emerging from the two left bays. Same discharge as above

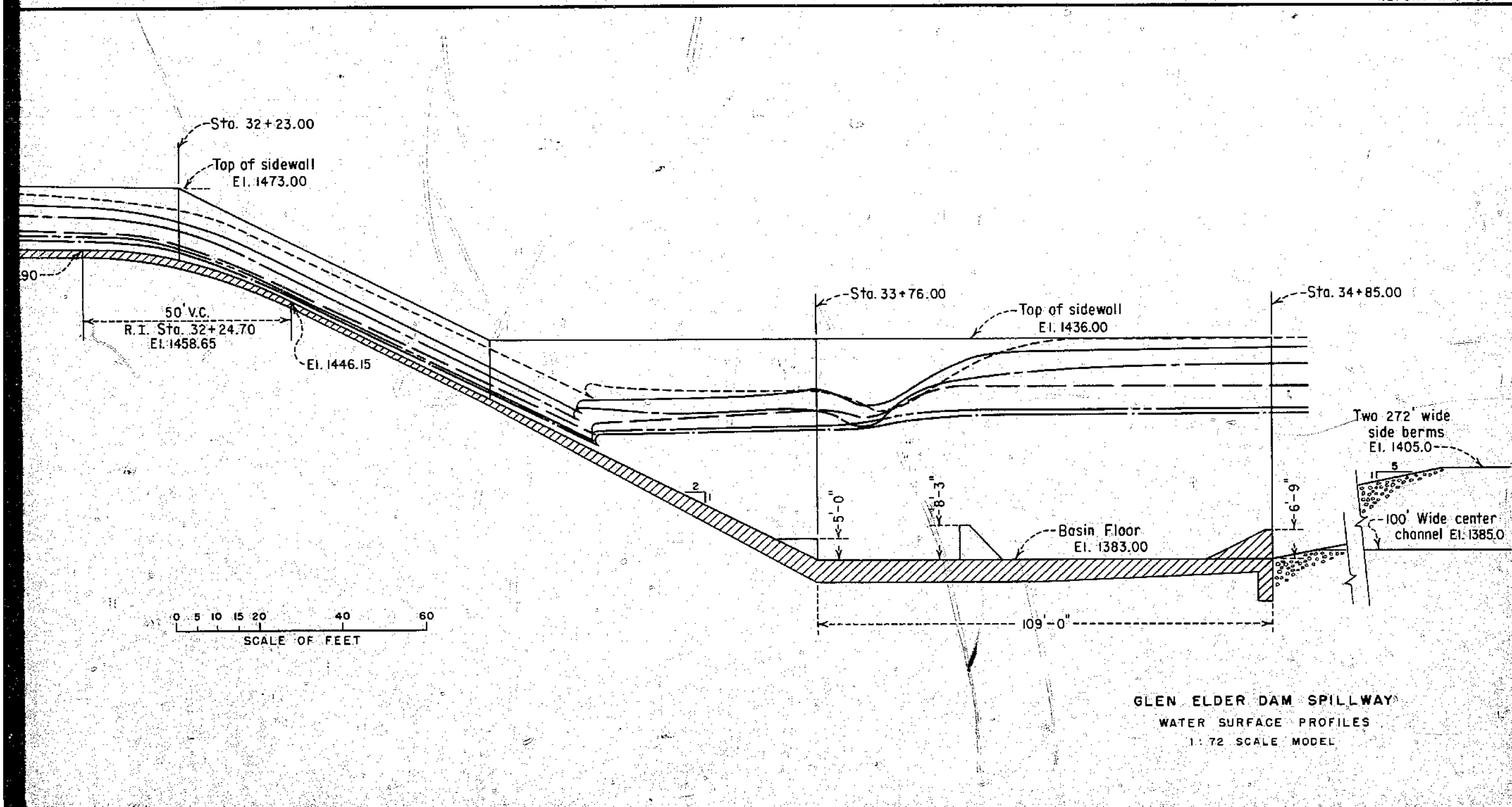


C. Maximum discharge through fully opened gates except left end gate closed, reservoir water surface El. 1492.2

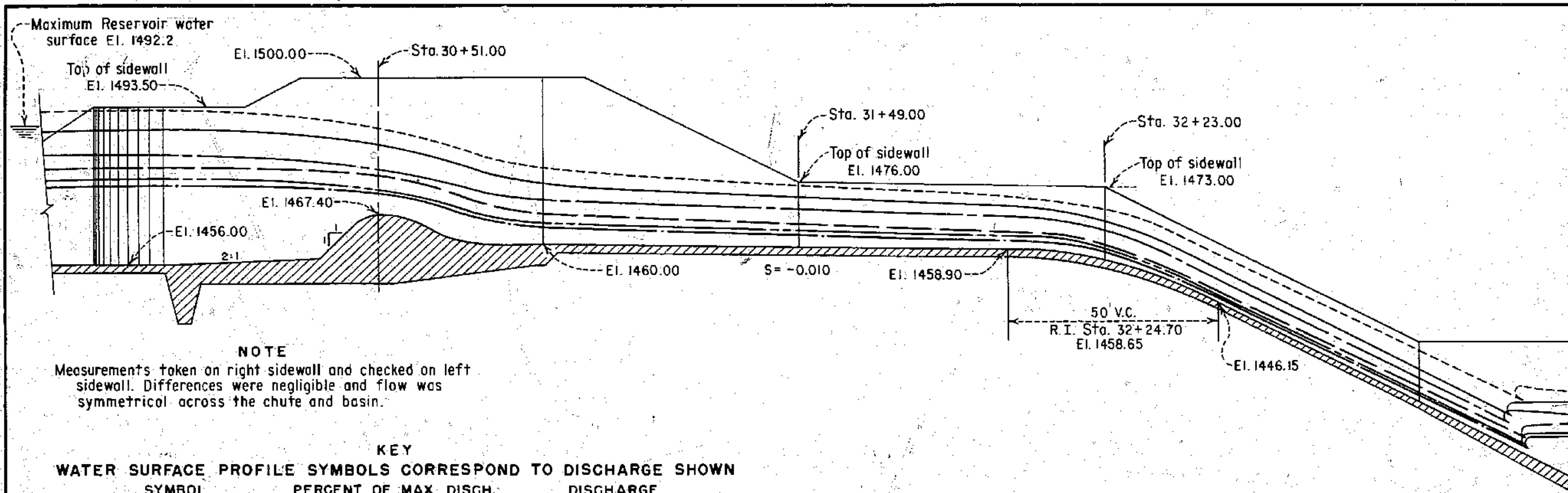
GLEN ELDER DAM
SPILLWAY

Flow Through Spillway Bays and on Chute

1-72 Scale Model



GLEN ELDER DAM SPILLWAY
WATER SURFACE PROFILES
1:72 SCALE MODEL



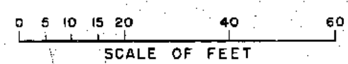
NOTE

Measurements taken on right sidewall and checked on left sidewall. Differences were negligible and flow was symmetrical across the chute and basin.

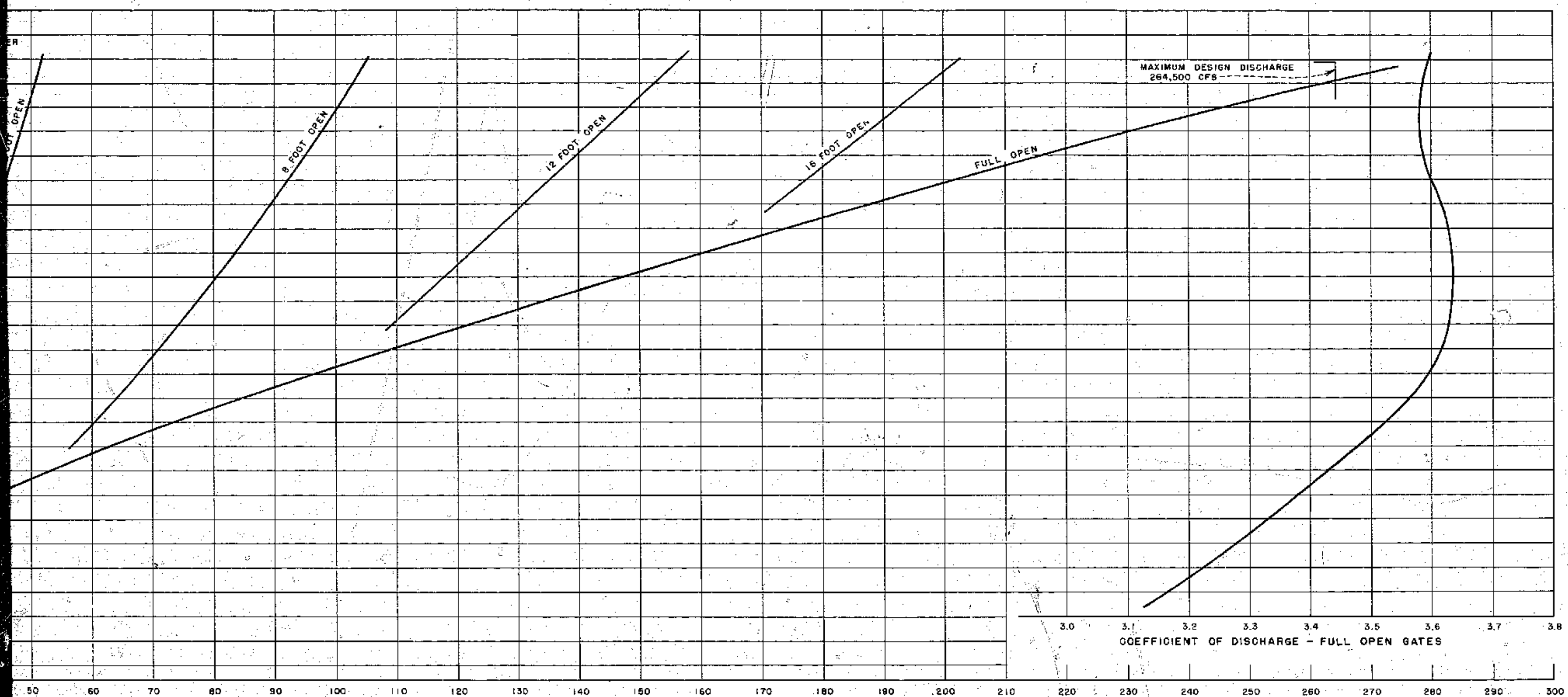
KEY

WATER SURFACE PROFILE SYMBOLS CORRESPOND TO DISCHARGE SHOWN

SYMBOL	PERCENT OF MAX. DISCH.	DISCHARGE
- - - - - -	125	330,625
———	100	264,500
———	75	198,375
— — —	50	132,250
—-—-	25	66,125
—·—·	19	50,000

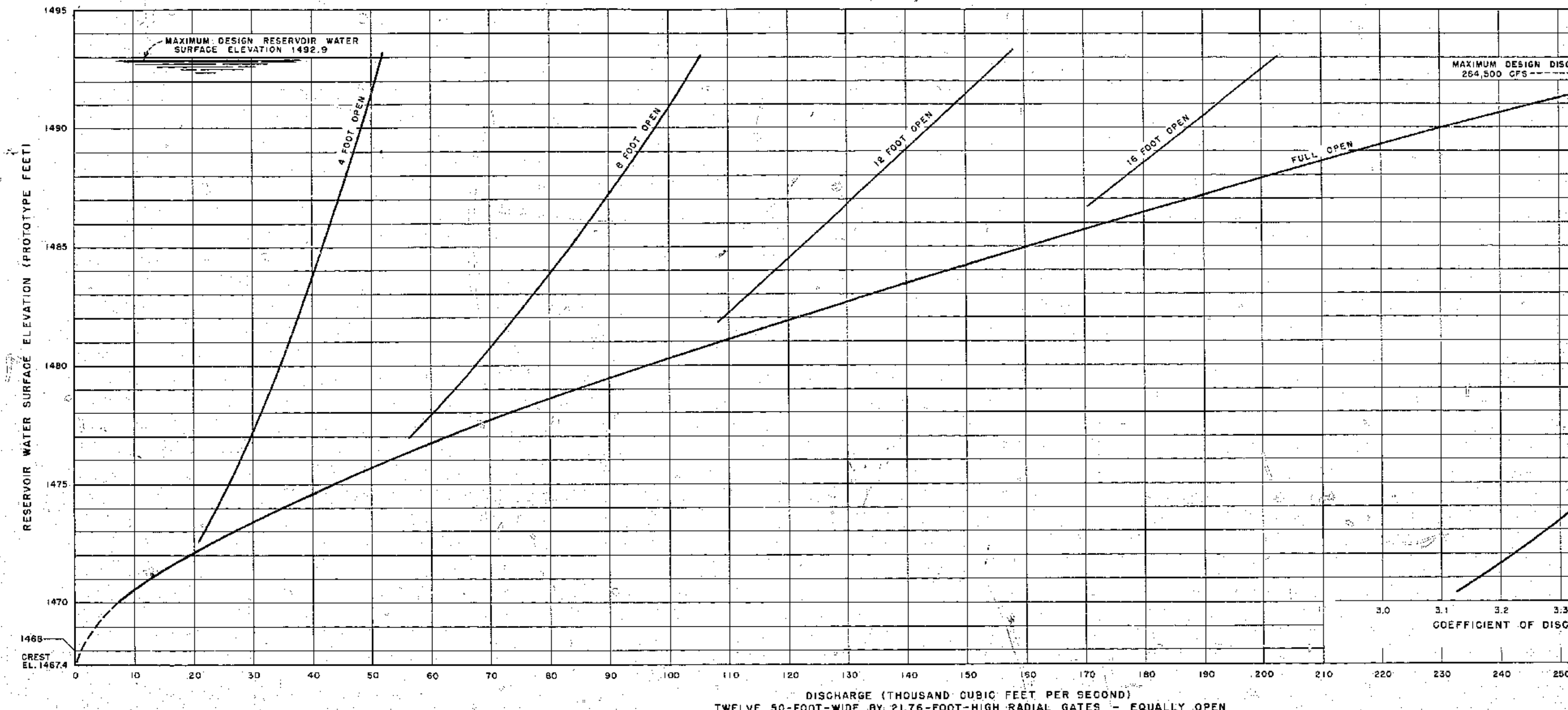


FRAME 2



ng the
corrected
n 25+11.0

GLEN ELDER DAM SPILLWAY
DISCHARGE CAPACITY
1:72 SCALE MODEL

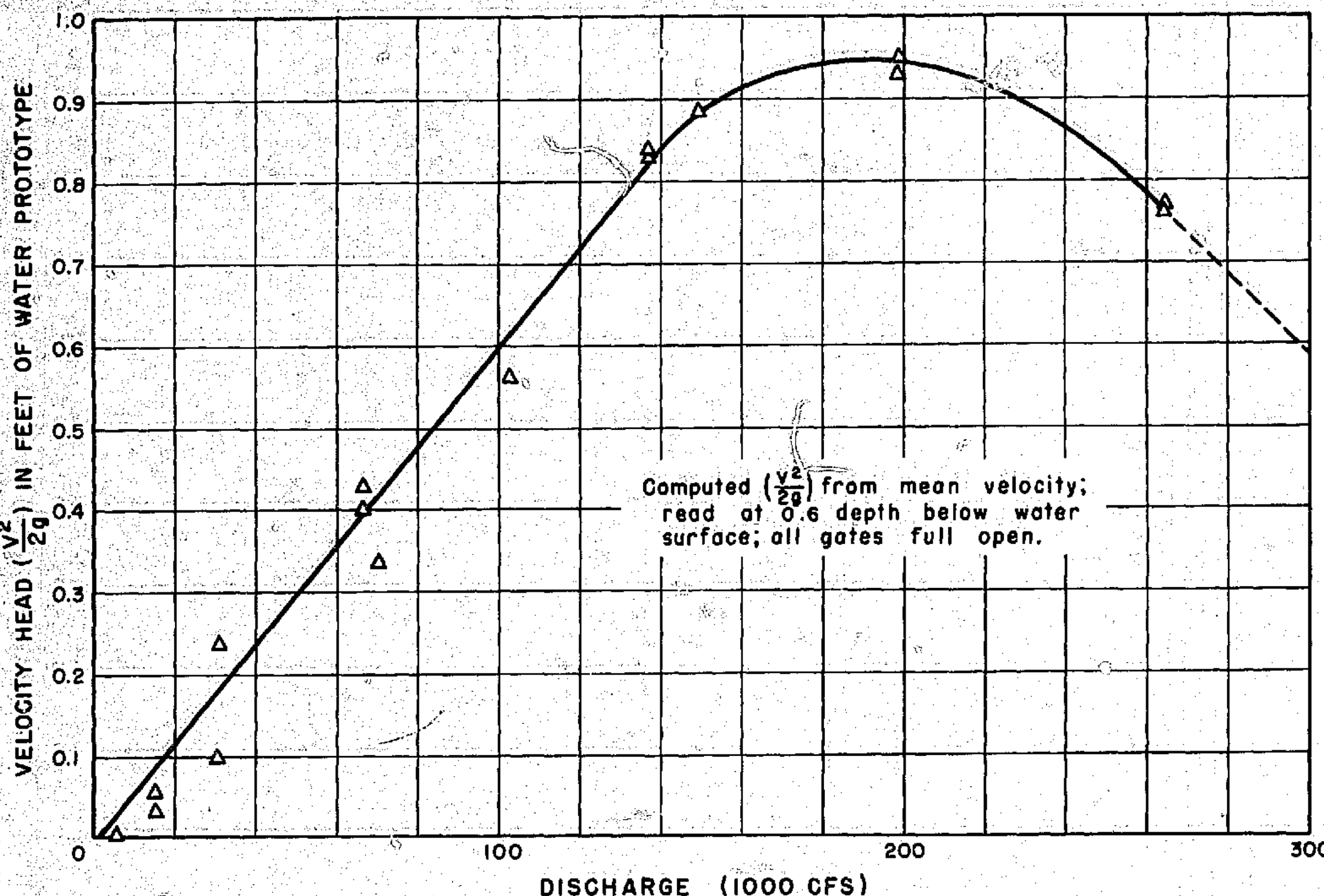


NOTES

Gate openings measured circumferentially along the arc of gate travel from the gate seat.
The reservoir water surface elevation was corrected for velocity head and measured at station 25+11.0 on the centerline of the approach channel.

GLEN ELDER
DISCHARG
1:72 S

FRAME 2



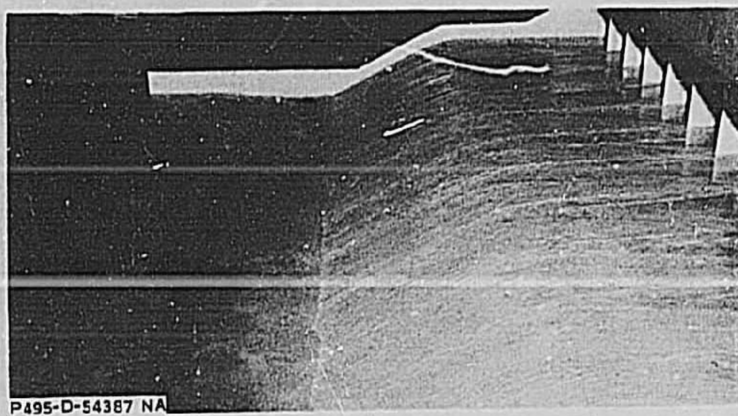
GLEN ELDER DAM SPILLWAY

VELOCITY HEAD OVER MODEL STILLING WELL INTAKE
FOR FULL OPEN GATES

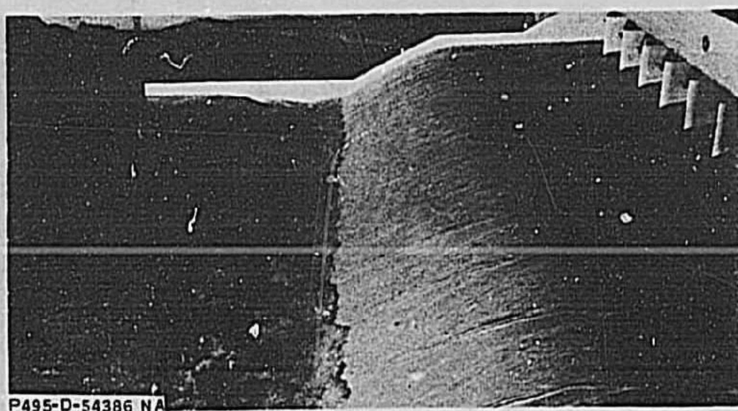
1 : 72 SCALE MODEL

FIGURE 18
REPORT HYD-561

Figure 19
Report Hyd - 561



Discharge 50,000 cfs with gates controlling
reservoir water surface El. 1482



Discharge 132,250 cfs with gates fully open
reservoir water surface El. 1482.9

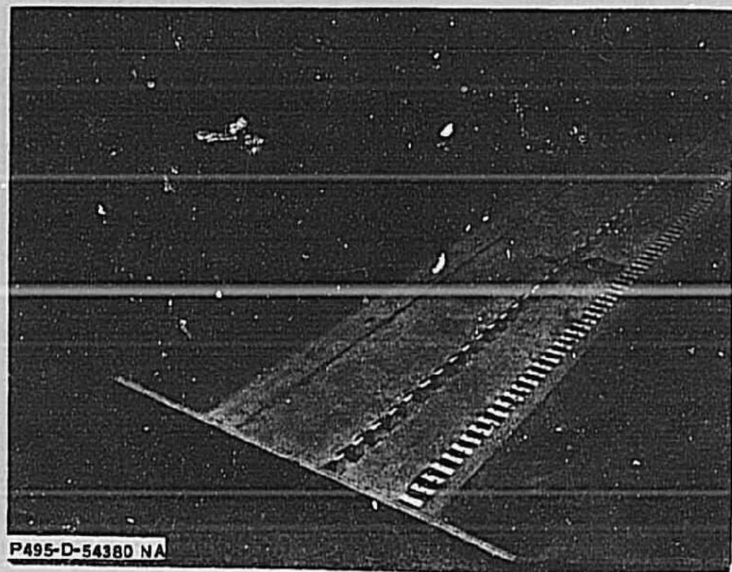
Discharge 264,500 cfs with gates fully open
reservoir water surface El. 1482.2

Chute and Stilling Basin Flow - Preliminary Design

GLEN ELDER DAM
SPILLWAY

1-72 Scale Model

Figure 20
Report Hyd-561



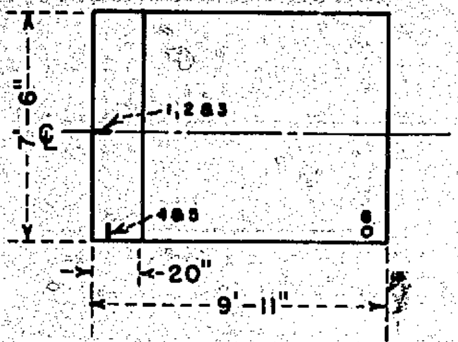
A. Downstream channel formed in sand prior to all erosion tests

B. Erosion after operation for 2 hours (prototype) at 264, 500 cfs

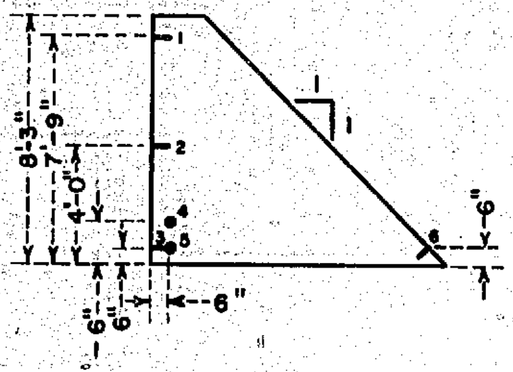
GLEN ELDER DAM
SPILLWAY

Channel Erosion - Preliminary Design

1-72 Scale Model



PLAN



ELEVATION

PIEZOMETER LOCATIONS & NUMBERS

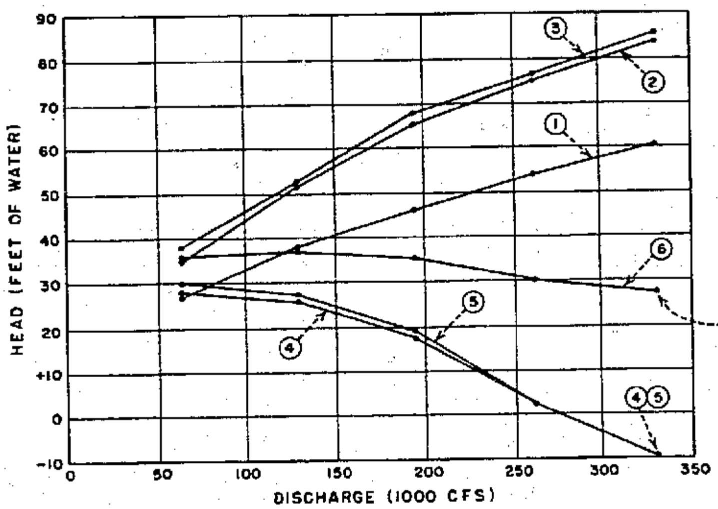
	Pressure in feet of water (Prototype)			
Discharge	66,700 cfs	132,400 cfs	198,200 cfs	265,200 cfs
Tailwater Elev.	1417 ft	1423 ft	1428 ft	1431 ft
Piezometer No.				
1	28	38	47	54
2	35	51	65	74
3	38	52	68	76
4	28	26	18	3
5	30	27	19	3
6	35	37	35	31

Notes: Pressures measured by water manometer. Maximum fluctuations 3 feet of water except for piezometers 4 and 5, where pressures fluctuated about 20 feet and averaged 9 feet subatmospheric for 125 percent of maximum discharge (333,200 cfs). Test pier was located near basin centerline.

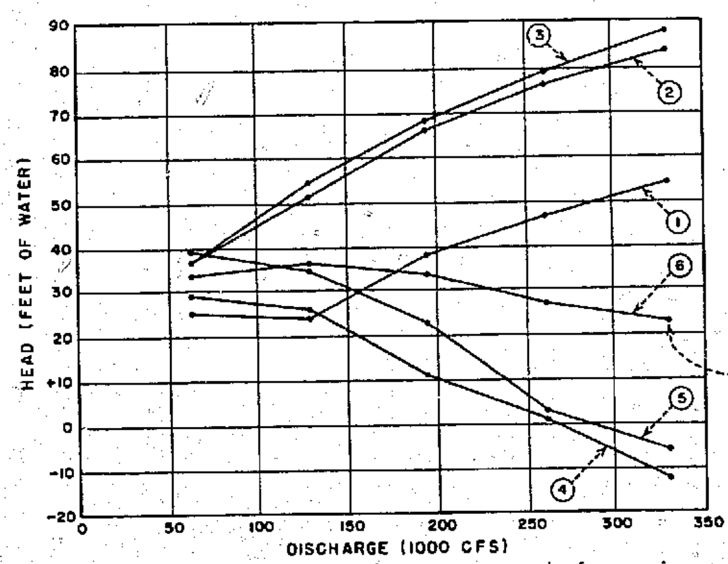
GLEN ELDER DAM SPILLWAY

AVERAGE PRESSURES ON PRELIMINARY BAFFLE PIER

1:72 SCALE MODEL



A. Average pressures read from water manometers



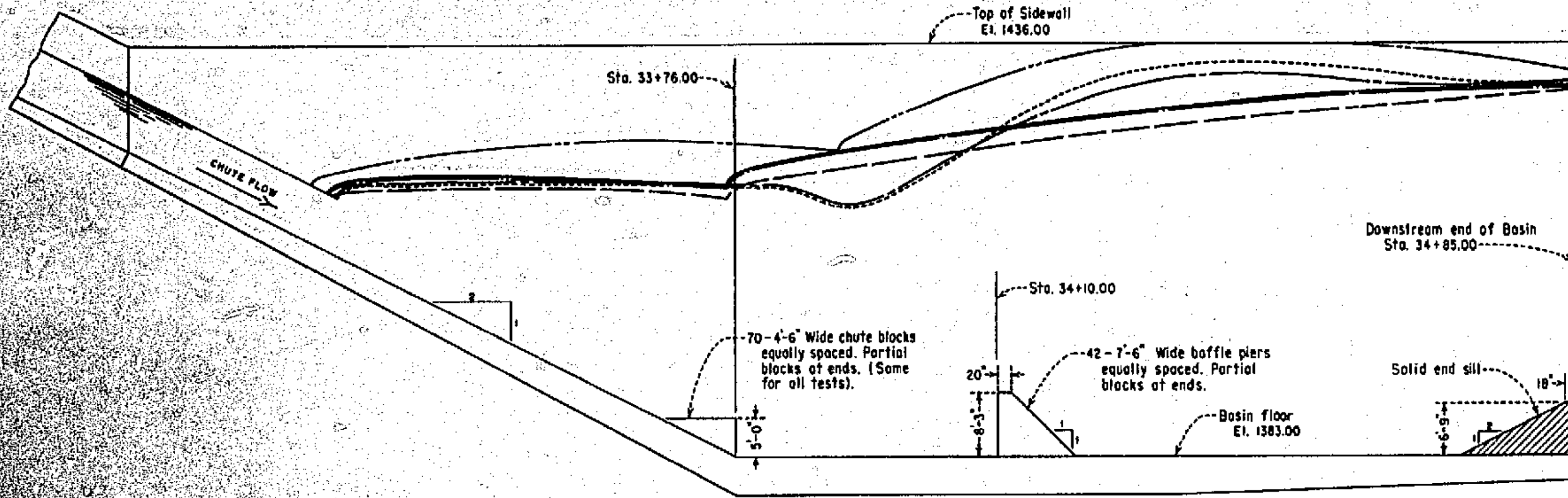
B. Average pressures read from paper record of averaging recorder connected to pressure transducers.

DISCHARGE (CFS)			66,700	132,400	198,200	265,200	333,200
PERCENT OF MAX. DISCH.			25	50	75	100	125
PIEZOMETER NUMBERS	1	Fluctuation[1]	7	18	28	40	50
		Frequency[2]	0.9	1.3	1.5	1.5	1.5
	2	Fluctuation	5	23	35	41	71
		Frequency	0.8	0.9	1.4	1.2	1.5
	3	Fluctuation	6	19	40	54	65
		Frequency	1.2	1.2	1.3	1.5	1.4
	4	Fluctuation	5	32	57	89	94
		Frequency	1.4	0.8	1.1	0.9	1.3
	5	Fluctuation	13	38	57	83	89
		Frequency	0.8	0.8	1.3	1.2	1.4
	6	Fluctuation	5	18	44	50	65
		Frequency	0.6	0.7	0.9	0.8	1.2

C. Dynamic pressures read from pressure transducers

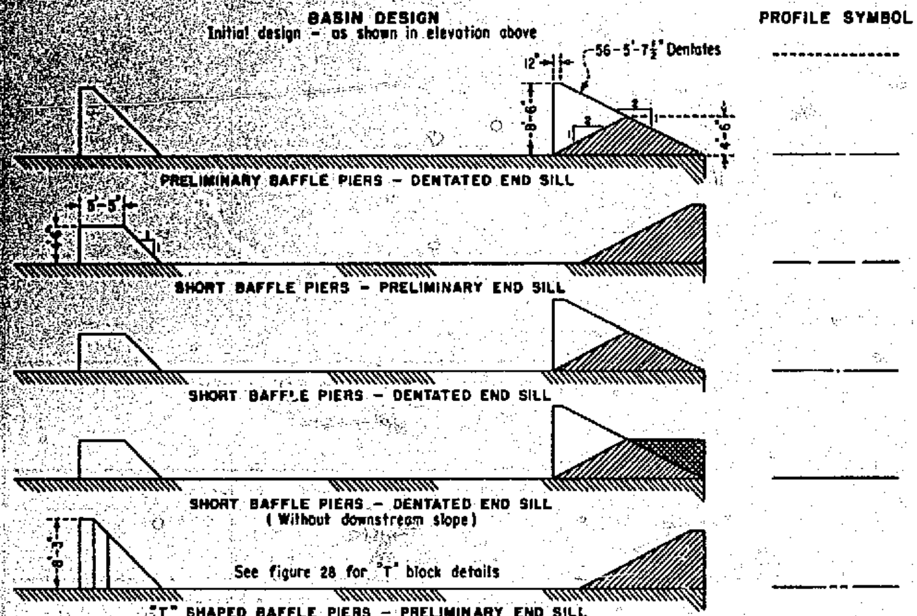
NOTES
1. Fluctuation - the total magnitude through which the pressures fluctuate (feet of water).
2. Frequency - the average frequency of fluctuations (cycles per second-prototype).

GLEN ELDER DAM SPILLWAY
DYNAMIC AND AVERAGE PRESSURES ON PRELIMINARY BAFFLE PIER
1:72 SCALE MODEL



WATER SURFACE PROFILE ELEVATION

0 5 10 20 30
SCALE OF FEET

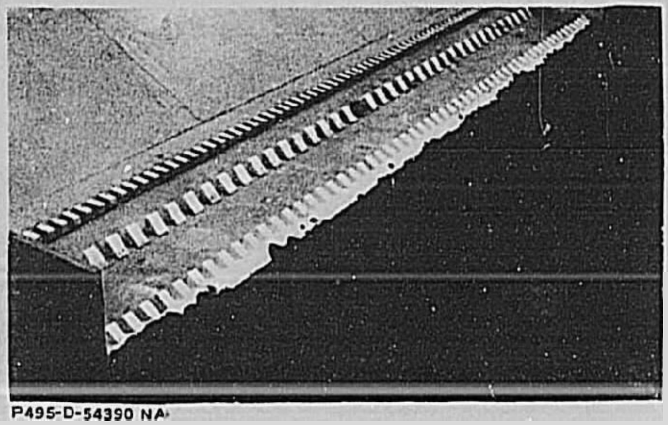


NOTE

Measurements taken on right sidewall and checked on left sidewall. Differences were negligible and flow was symmetrical across the basin. Discharge 264,500 cfs Tailwater Elevation 1431

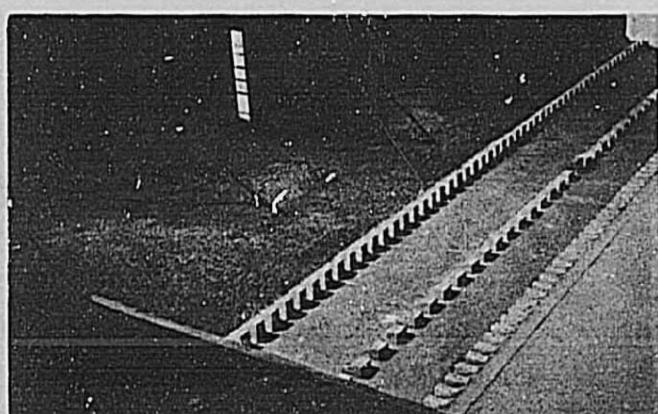
GLEN ELDER DAM SPILLWAY
STILLING BASIN WATER SURFACE PROFILES FOR DIFFERENT BAFFLE PIER AND SILL ARRANGEMENTS
1:72 SCALE MODEL

Figure 24
Report Hyd-561



A. Erosion after operation for 2 hours (prototype) at 132,250 cfs tailwater at El. 1423. Note bed material deposited against the end sill (preliminary baffle piers and dentated end sill.)

B. Above test followed by 264,500 cfs for 8 hours (prototype) tailwater at El. 1431



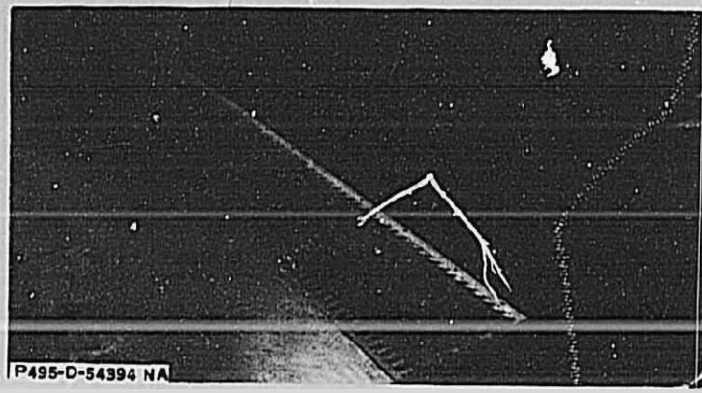
C. Erosion after operation for 8 hours (prototype) at 264,500 cfs tailwater El. 1431. Note the four raised dunes downstream for sill. (Short baffle piers and dentated end sill.)

GLEN ELDER DAM
SPILLWAY

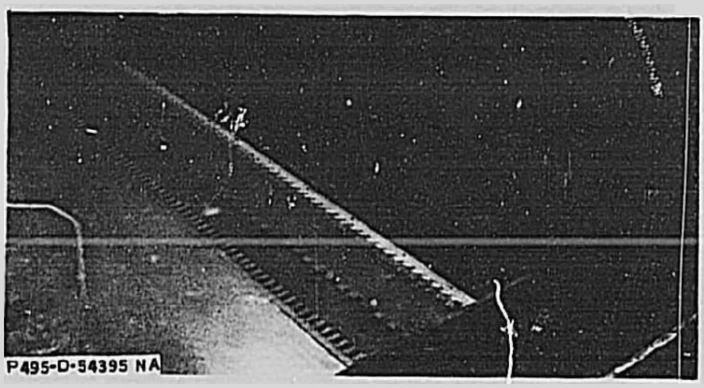
Channel Erosion with Dentated End sill, Preliminary and Short Baffle Piers

1-72 Scale Model

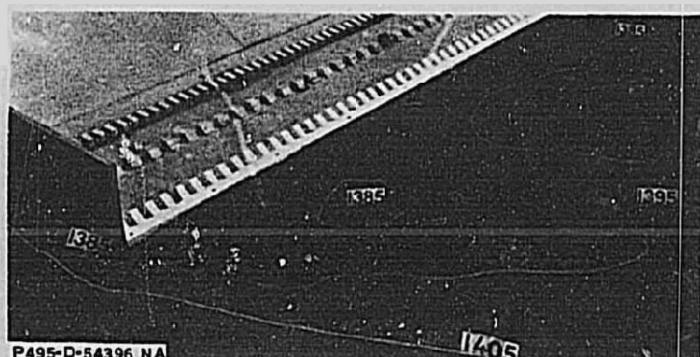
Figure 25
Report Hyd-561



A. After 2 hours (prototype) operation at 132,250 cfs tailwater El. 1423 note sloughing of side slopes with negligible erosion



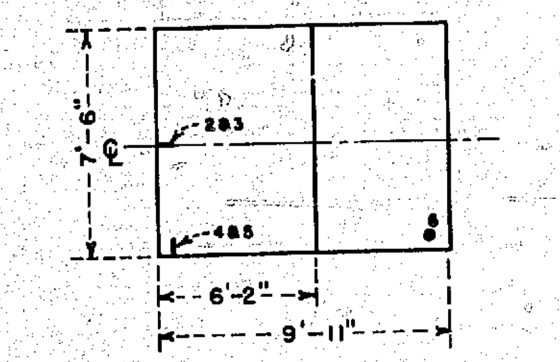
B. After 8 hours (prototype) operation at 264,500 cfs tailwater El. 1431. Erosion pattern similar to preliminary basin



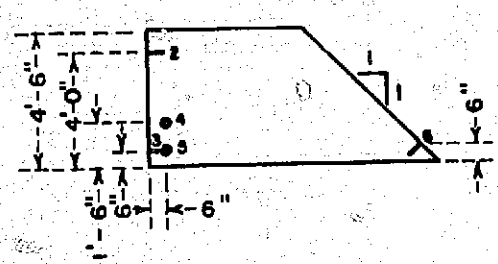
C. Closeup of erosion at the end of the basin training wall

GLEN ELDER DAM
SPILLWAY

Channel Erosion - Short Baffle Piers and Dentated End Sill
1-72 Scale Model



PLAN



ELEVATION

PIEZOMETER LOCATIONS & NUMBERS

	Pressure in feet of water (Prototype)		
Discharge	264,500 cfs	264,500 cfs	264,500 cfs
Tailwater Elev.	1431 ft (normal)	1439 ft (high)	1427 ft (low)
Piezometer No.			
2	59	60	57
3	69	69	66
4	-4	18	-15
5	-4	19	-14
6	31	42	25

Notes: Average pressures measured by water manometer. Maximum fluctuations 2 feet of water. Test pier was located near basin centerline and the water depth over the pier was about 30 feet.

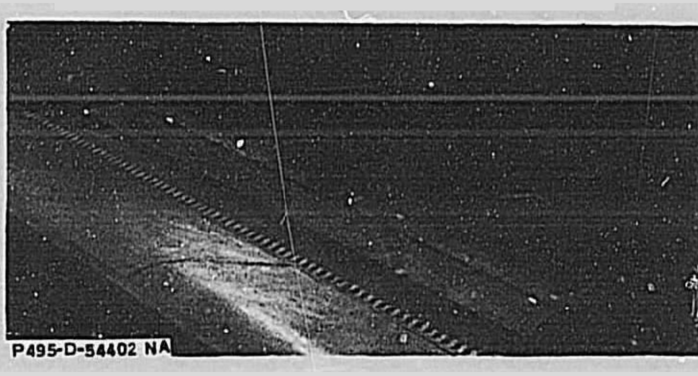
GLEN ELDER DAM SPILLWAY

AVERAGE PRESSURES ON SHORT BAFFLE PIER

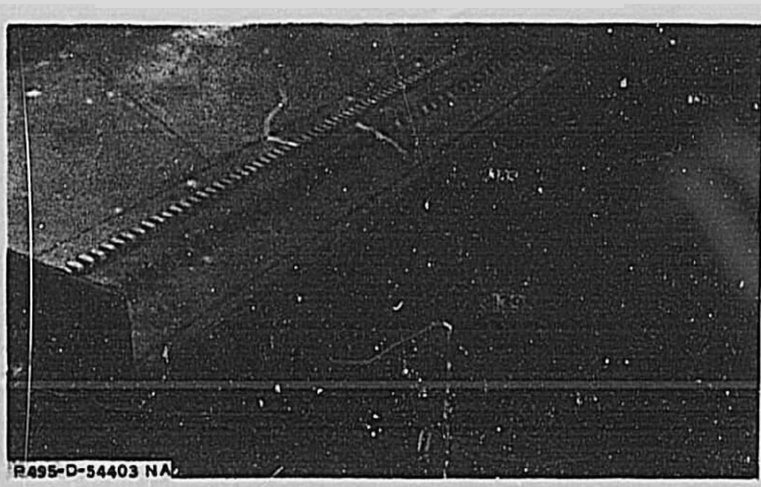
1:72 SCALE MODEL

Figure 27
Report Hyd-561

A. After 2 hours (prototype) operation at 132,250 cfs tailwater El. 1423. Smooth channel downstream from preliminary basin and dunes starting to form downstream from the "T" piers (right half of basin)



B. After 8 hours (prototype) operation at 264,500 cfs tailwater El. 1431. Note dunes or ridges deeply cut in channel downstream from "T" piers

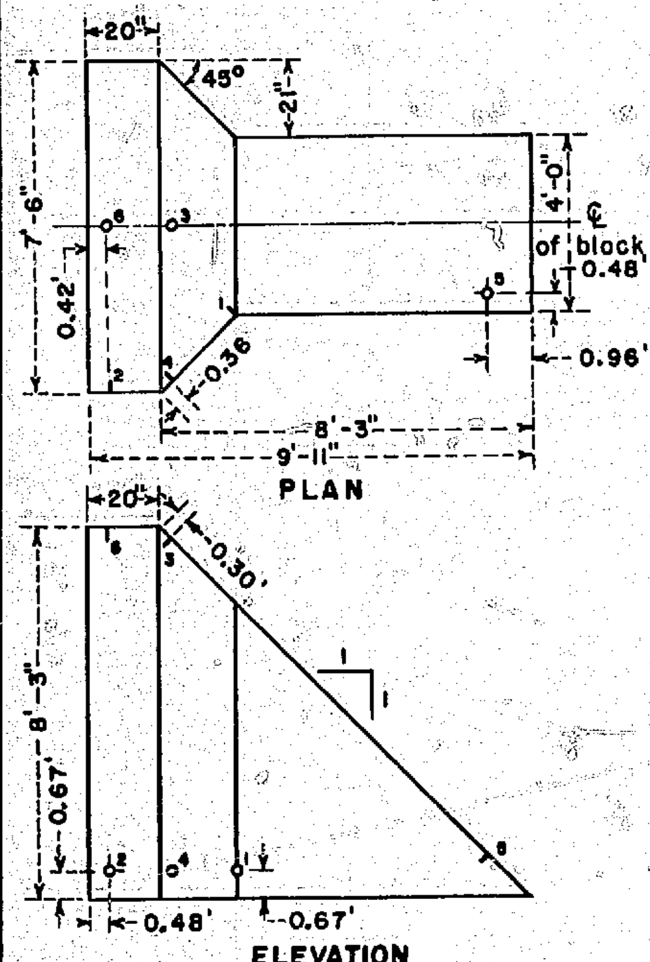


C. Above test flow - Channel bed erosion downstream from the "T" piers

GLEN ELDER DAM
SPILLWAY

Comparative Erosion Test - Preliminary and "T" Baffle Piers

1-72 Scale Model



PIEZOMETER LOCATIONS & NUMBERS

Pressure in feet of water (Prototype)			
Discharge	264,500 cfs	264,500 cfs	132,250 cfs
Tailwater Elev.	1431 ft (normal)	1427 ft (low)	1423 ft (normal)
Piezometer No.			
1	26	20	33
2	13	8	29
3	21	11	26
4	22	16	32
5	32	24	34
6	22	11	26

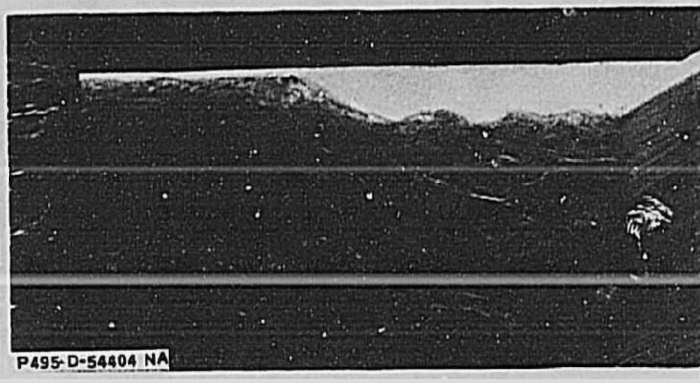
Notes: Maximum pressure fluctuations, as measured by water manometers, were 7 feet of water. Test pier was located near basin centerline and the water depth over the pier was about 40 feet.

GLEN ELDER DAM SPILLWAY

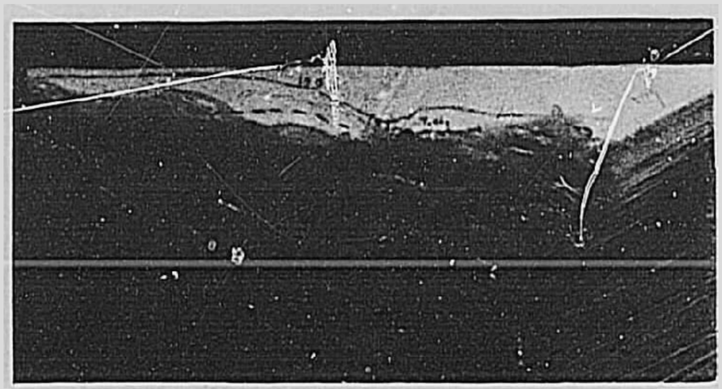
AVERAGE PRESSURES ON "T" BAFFLE PIER

1:72 SCALE MODEL

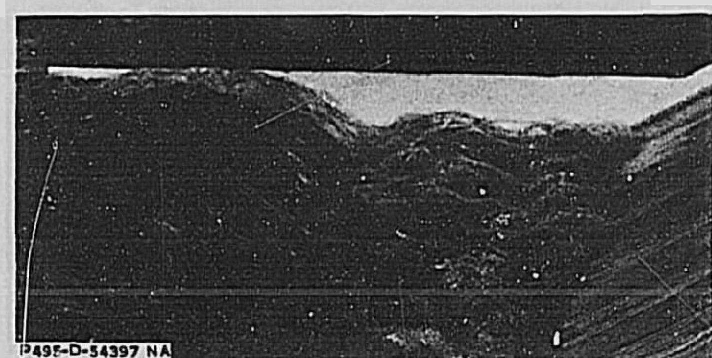
Figure 29
Report Hyd-561



Preliminary baffle piers - Discharge 264,500 cfs tailwater El. 1431 gates fully open



Short baffle piers - with above discharge



"T" baffle piers - with above discharge

GLEN ELDER DAM
SPILLWAY

Effect of Different Baffle Piers on Basin Flow

1-72 Scale Model

7-1750
(10-64)

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-5}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 845-237

ABSTRACT

Model studies indicated that the initial design of the Glen Elder Dam spillway was adequate for flows up to and including the 264,500 cfs maximum discharge. Spillway discharge is controlled by twelve 50-foot-wide by 21.76-foot-high radial gates and the energy is dissipated by a hydraulic jump stilling basin (Type III). Total drop in elevation from spillway crest to basin floor is 84.4 feet. Tests performed and results recorded include velocity and water surface profiles in the approach channel, water surface profiles throughout the structure, pressures on the baffle piers, erosion in the approach and downstream channels, and discharge capacity and coefficients for the spillway. Training dikes for the approach channel, and five different baffle pier and end sill arrangements in the stilling basin were tested. The shortened baffle pier was used in construction.

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HYD-561
Arris, W. F.
HYDRAULIC MODEL STUDIES OF THE SPILLWAY--GLEN ELDER DAM
MISSOURI RIVER BASIN PROJECT, KANSAS
USBR Lab Report Hyd-561, Hydraulics Branch, Division of Research, June 6, 1966. Bureau of Reclamation, Denver, 13 p, 1 tab, 29 fig

DESCRIPTORS-- *dentated sills/ hydraulic structures/ *stilling basins/ discharge coefficients/ discharge measurement/ flow/ Froude number/ hydraulic jumps/ hydraulic models/ open channel flow/ spillway crests/ *water surface profiles/ velocity distribution/ erosion/ radial gates/
IDENTIFIERS-- *baffle piers/ hydraulic design/ Glen Elder Dam, Kan./ Missouri River Basin Project

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